Soil Moisture and Crop Production

Results of Experiments Conducted on the Dominion Experimental Station, Swift Current, Sask.

By

S. BARNES AND E. S. HOPKINS

DIVISION OF FIELD HUSBANDRY
DOMINION EXPERIMENTAL FARMS

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TABLE OF CONTENTS

	Page
Importance of soil moisture	3
Fluctuations in wheat yields through variations in moisture supply	3
Precipitation in a typical "Dry Farming" area	5
Factors controlling precipitation in a "Dry Farming" area	7
Water used in the production of a crop of wheat	8
Experimental methods used at Swift Current in the study of soil moisture	9
A comparison of experimental methods	14
Soil moisture and grain rotations	18
The summer-fallow	22
The summer-fallow and weed growth	23
Moisture conserved by the summer-fallow	26
Wheat yields as affected by the growth of weeds	27
Soil moisture as affecting grass and clover crops	30
Soil moisture in a wheat, sweet clover, summer-fallow rotation	30
Grass crops in a crop rotation	32
Corn and sunflowers in rotation with wheat	34
The water requirements of crops	36
The drought resistence of crops	42
Soil moisture and crop forecasting	43
The indirect effect of fertilizers on soil moisture	44
Conclusion	45

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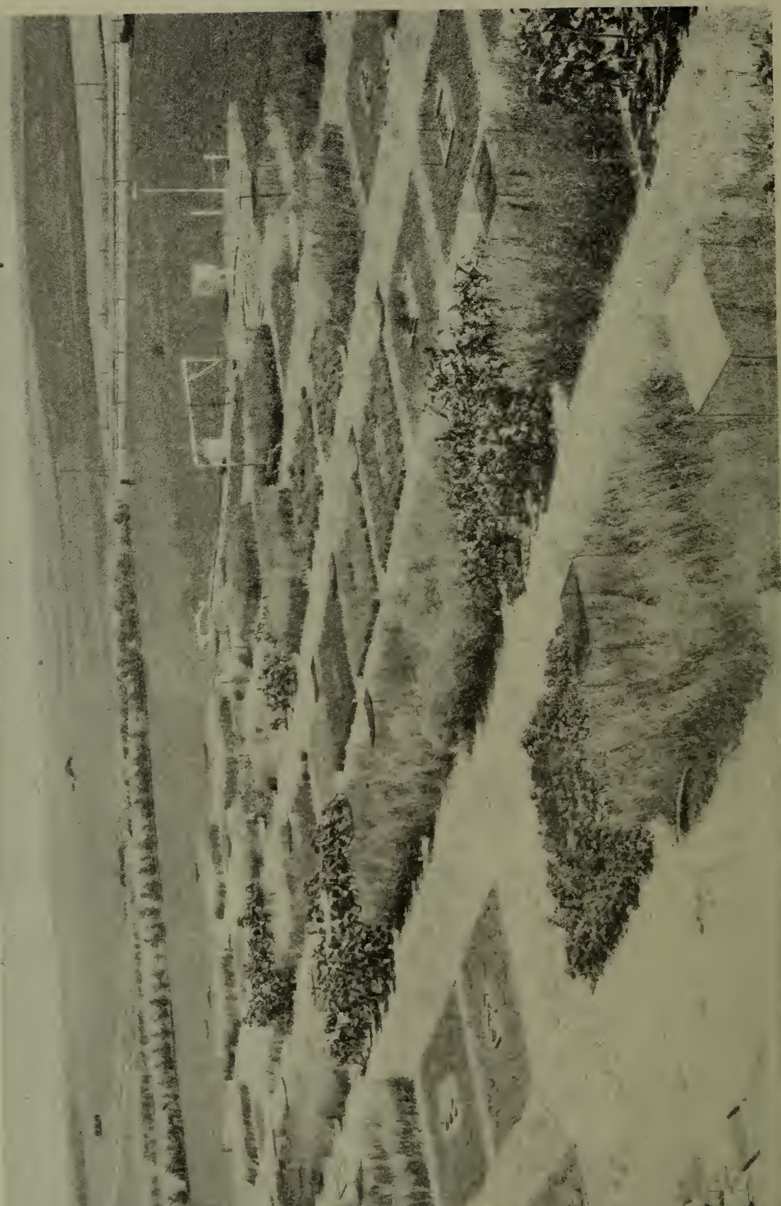


Soil moisture experiments on the Dominion Experimental Station, Swift Current, Sask. General view of plots.

SOIL MOISTURE AND CROP PRODUCTION

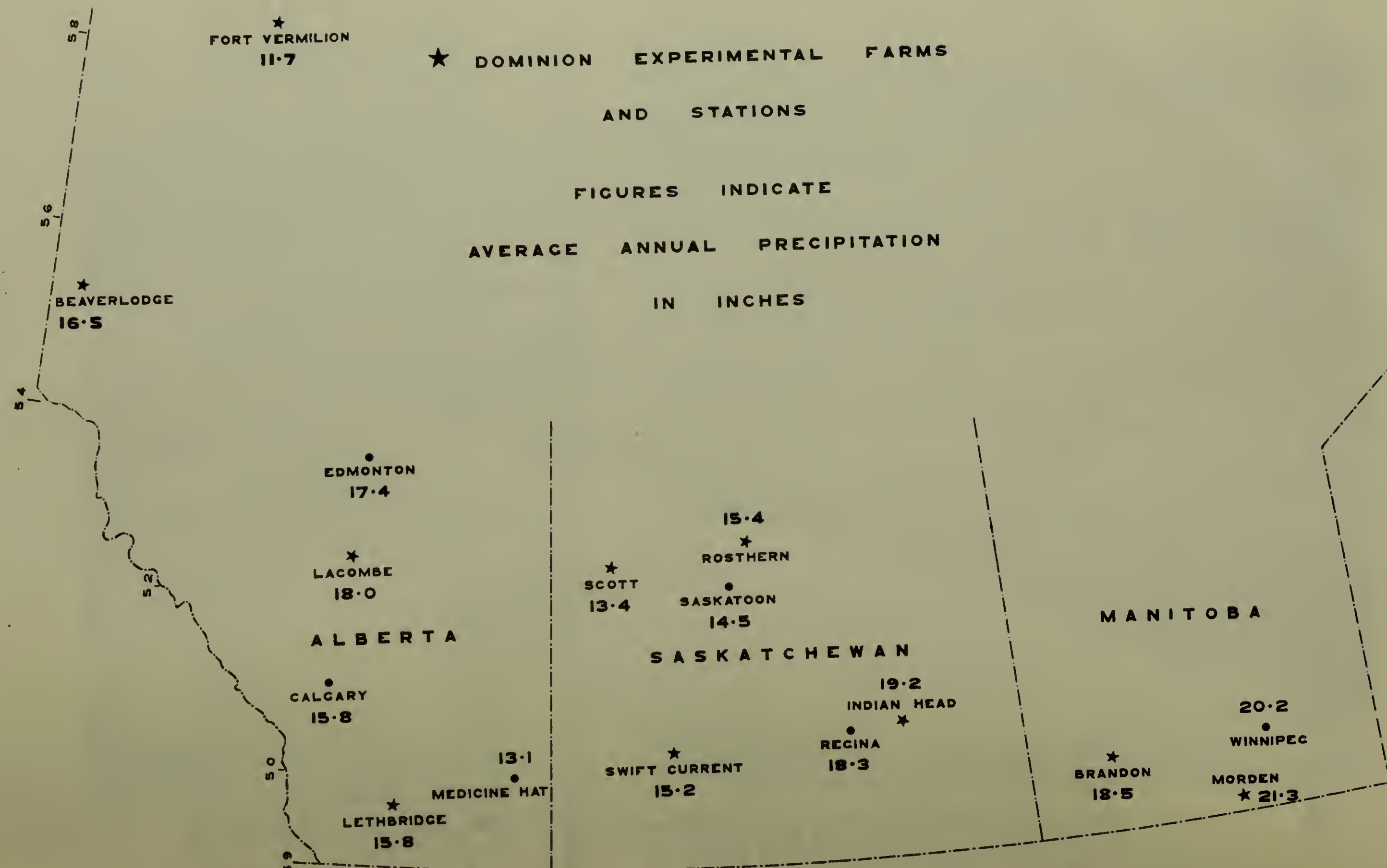
BY S. BARNES AND E. S. HOPKINS

IMPORTANCE OF SOIL MOISTURE

Soil moisture, its conservation and use by plants, forms one of the most important factors in successful crop production in Western Canada. Throughout the three Prairie Provinces in Manitoba, Saskatchewan and Alberta the average annual precipitation ranges from 13 to 20 inches. In the eastern portion of Canada the average annual range is from 30 to 40 inches. On this account farming practices in Western Canada, or specifically in the Prairie Provinces, differ considerably from those employed in the eastern part of the Dominion. The climate of the prairie areas is characterized by periods of moisture deficiency, especially in certain seasons, and special methods of soil cultivation are necessary to conserve moisture and to ensure profitable crop yields. These methods are not of so great importance in the eastern portion of Manitoba, nor in the wooded sections of all three provinces where moisture losses are not excessive, but on the open plains the strict observance of moisture conservation is an insurance against the evil effects of a dry season. The peculiar soil cultural methods adopted in such cases have been grouped together under the heading of "Dry-Farming". The term is a misnomer as it is suggestive of the absence of moisture in which crop production would be impossible, but as a more appropriate term has not been proposed the expression "Dry-Farming" is now in general use.

FLUCTUATIONS IN WHEAT YIELDS THROUGH VARIATIONS IN MOISTURE SUPPLY

The type of agriculture in Western Canada is essentially that of the production of spring-seeded cereals. Of the whole cultivated area in 1926, 96 per cent was used for grain production, with wheat as the principal and most profitable crop. In seasons of favourable moisture conditions good yields are secured, while, on the other hand, in unfavourable seasons, a light harvest may result unless special care has been taken to conserve the limited moisture supply. As an indication of the great variation in grain yields caused by deficient, or abundant rainfall the following examples may be mentioned. At the Dominion Experimental Station, Lethbridge, Alta., the yield of wheat on summer-fallow land has fluctuated between 2·2 bushels per acre in 1919 and 63·1 bushels in 1915. At another Station, Scott, Sask., the variation has been from 2·7 bushels in 1918 to 40·0 bushels in 1915.



Skeleton map of prairie.

PRECIPITATION IN A TYPICAL "DRY FARMING" AREA

The efficient utilization of soil moisture in dry farming areas is assisted to some extent by a peculiar distribution of the monthly precipitation. Maximum amounts of precipitation, on the average, occur during the months of June and July, while relatively small amounts are received during the winter months. Maximum precipitation, therefore, takes place when vegetation can use large quantities of water to good advantage. On page 6 is presented a chart showing the average monthly precipitation throughout the year at Swift Current, Saskatchewan. The monthly averages at Ottawa, Ont., representing Eastern Canada, are also shown.

As the term "inches of precipitation" may not be quite clear to some readers a short explanation may not be out of place here. Where facilities are not available for determining how much moisture has fallen during a rain storm such descriptive expressions as "a heavy rain", "a good soaking rain" or even "a million dollar rain" are not uncommon. These expressions, however, give only a vague idea of the amount of rain which actually fell and the probable benefit to growing crops.

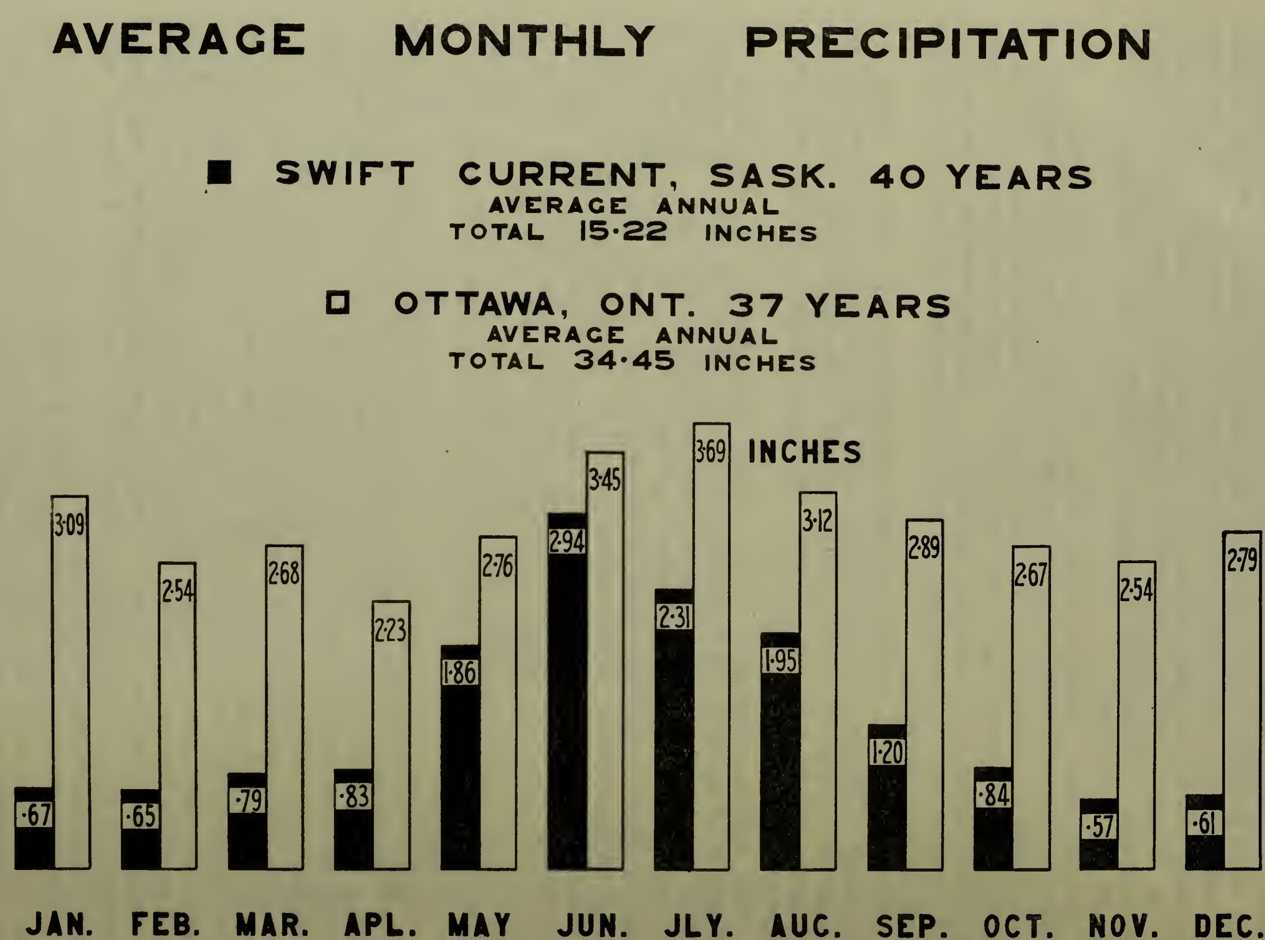
Wherever rainfall records are kept measurements are made by means of a rain gauge. This is a comparatively simple instrument. It is set out exposed in a suitable spot so that rain will be caught in the cup-shaped portion of the instrument and be stored inside, where provision is made to prevent evaporation before a reading can be made.

The amount registered by the gauge is expressed, for convenience, in hundredths of an inch and is written in decimal form. In this way a rainfall of 0·23 inch represents twenty-three one-hundredths of one inch. A rainfall of 1·07 inches represents one and seven one-hundredths. The figures indicate the depth to which the ground would be covered if all the rain which fell were to remain on the surface. Under natural conditions some moisture from a rainfall is absorbed by the soil while a portion may run off into nearby streams or depressions. By the use of a rain gauge each shower has a distinctive significance. A rainfall of 0·25 inch or less may prove of very little benefit to a crop, even though its arrival might justify the expression "a heavy rain," because evaporation afterwards may prevent much of the moisture from penetrating far into the ground.

Snowfall, as a rule, cannot be measured conveniently by means of the gauge on account of the drifting caused by wind action. It is usually estimated by the use of an ordinary rule. The depth of snow is reduced to the equivalent of rainfall by dividing the amount recorded by ten. In this way $4\frac{1}{2}$ or 4·5 inches of snow is equivalent to 0·45 or forty-five one-hundredths of an inch of rain.

The term precipitation is generally understood to include rainfall and snowfall combined, with the latter, of course, reduced to its equivalent of rainfall. Precipitation is frequently a local occurrence. The rainfall registered at one locality may have entirely missed another only a few miles distant. The total amounts received, however, indicate that local variations tend towards uniformity in the course of time. Generally speaking, the greatest total annual precipitation falls in the eastern portion of the three Prairie Provinces, while lesser amounts are received further west.

The average annual precipitation at Swift Current, where records have been kept since 1886, is 15·22 inches. This amount, as explained above, includes snowfall reduced to the equivalent of rainfall. The greatest amount recorded in one year was 24·55 inches in 1891 and the least 9·66 inches in 1894. During what may be termed the four crop growing months of April to July, the average rainfall is 7·94 inches. In this case, as with the yearly average, wide fluctuations have occurred.



Monthly precipitation.

The experiments described in this bulletin have been carried out on the Dominion Experimental Station at Swift Current in southwestern Saskatchewan. In this area the production of spring wheat forms the chief agricultural activity. This bulletin deals chiefly, therefore, with the effect of moisture upon the wheat crop.

FACTORS CONTROLLING PRECIPITATION IN A DRY-FARMING AREA

The geographical location of dry-farming areas in Western Canada, with respect to the Rocky mountains, accounts chiefly for the difference in amount of precipitation over those areas as compared to the precipitation in Eastern Canada. The mountains intercept moisture so that rain falls on the western slopes instead of passing over to the prairies.

From all bodies of water moisture is being evaporated continually by heat from the sun. The magnitude of this process, throughout the world, is such that around 16,000,000 tons of water is converted into vapour every second.* This moisture is present in the atmosphere and frequently is visible as clouds. The atmosphere surrounding the world is never at rest, but moves continuously from areas of high barometric pressure to areas of low pressure and these areas in turn change in a direction approximately from west to east. In this movement, of course, the water vapour is caused to join.

The presence of moisture in the atmosphere has been brought about by the action of heat upon water. If the vapour could be cooled a reverse action would take place and water would appear in the form of rain. The mechanism by which rain is formed is of particular interest to farmers in dry-farming areas who would, at times, appreciate some means for rainfall control. The possibility of producing rain artificially has always been attractive and much money has been wasted on so-called "rain-makers," but a moment's investigation will indicate the futility of any attempt to produce rain in even moderate amounts. To convert into vapour enough water to give one inch of rainfall over 640 acres of land requires as much heat as would be produced by the combustion of over 5,000 tons of coal.† To transform this vapour back into water, that is as rain, would require an equal expenditure of energy, which appears to be an expensive proposition.

Under natural conditions the factors involved in the production of rain are of great magnitude. Warm, moisture-laden air coming from the Pacific is caused to rise in order to pass over the mountains. In doing so the air loses a considerable proportion of its heat. In other words, the air is cooled and as a result some of the moisture it contained falls as rain. Comparatively dry air then passes on eastwards. Fortunately this action is modified somewhat during the summer months. At this time the soil is warm. In passing over the land and before the mountains are reached moist air becomes still further warmed. This additional heating offsets the subsequent cooling caused by the passage over the mountains. At this time of the year Pacific coast points receive the minimum amounts of precipitation. A chart showing monthly precipitation for Vancouver, for example, set out similarly to that shown on page 6 for Swift Current, would be reversed. High precipitation occurs in Vancouver during the early and later months of the year and is at a minimum during June, July and August.

On the prairies rain is produced by the cooling of moist air coming as a rule from the west. This may occur in an area over which there happens to be low barometric pressure. The incoming air expands and rises, thereby parting with

* Rain making and other Weather Vagaries, by W. J. Humphreys.
† J. Patterson in Farmers' Advocate, Sept. 21, 1921.

some of its heat with the formation of rain. A similar action may take place, and frequently does, outside an area of low pressure due to the inflow of cold air from the north.

Variations in barometric pressure, air temperature and movement cause variations in the amount of precipitation. The complexity of these factors may be gauged from the fact that in no two years, during the past forty, has the precipitation at Swift Current been the same. The possibility of the farmer, or anyone else, being able to exercise control over the weather appears, for the present at least, entirely out of the question.

WATER USED IN THE PRODUCTION OF A CROP OF WHEAT

When considering methods for the efficient utilization of soil moisture by crops, the first question arising is, how much water is required to produce a crop? Under the weather conditions prevailing in southwestern Saskatchewan this question can be answered readily by the brief statement that it is as much as the crop can secure. That there is no definite quantity of water required to produce a crop of wheat is indicated by the yearly fluctuations of both rainfall and wheat yields. The experiments at Swift Current, carried through seven successive seasons, in which moisture conditions were representative of an extensive period, give an indication of the quantities of water used in the production of wheat. On land previously summer-fallowed from 1,000 to 1,974 pounds of water have been used in the production of one pound of grain. Expressed another way for each bushel of grain 30 to 59·4 tons or 150 to 297 barrels of water were used. Wheat produced on stubble land, that is wheat which followed a previous crop of wheat, required from 35·5 to 89·7 tons of water for each bushel of grain. The spread in each case, it might be mentioned, is due to the difference in amount of rainfall and available soil moisture each season. It appears from the above figures that more water is used to produce a bushel of grain from stubble land than from summer-fallow land, yet the summer-fallow land always contains more moisture. This apparent paradox is explained by the much lower yield obtained from the stubble land as compared to the quantity of water consumed. This matter will be discussed in greater detail under the heading " water requirements of crops " on page 36. The quantities of water given as necessary in the production of a bushel of wheat will appear less startling when expressed as inches of rainfall. As one inch of rainfall over an acre is equivalent to 113 tons of water, each inch of available moisture has resulted in a yield of wheat from summer-fallowed land of 1·91 to 3·77 bushels and from stubble land 1·26 to 3·19 bushels. On this basis the average annual precipitation should be sufficient to ensure profitable yields of crops. It must be remembered, however, that the year's precipitation is subject to several losses, some of which are unavoidable.

Spring-seeded grain crops can make effective use of moisture which falls as rain during the months of April to July, and in some cases also part of August, or during what is termed the growing period. That which is received after this time can be stored in the soil for the next season's crops. In all cases, however, part of the precipitation is dissipated in various ways and cannot be made available to crops.

The value of snow in augmenting available soil moisture appears to have been overestimated, although under some conditions it is distinctly useful. In some of the grain growing areas of European Russia, climatic conditions resemble those on the prairies of Western Canada. There, as is sometimes the case here, a deficiency of moisture occurs and some means for moisture conservation are necessary. To accomplish this various schemes to trap snow have been employed in the belief that the soil would benefit by the snow moisture. Hedges to form

snow traps have been planted around the fields. Plants, such as corn and sunflowers, have been seeded in triple rows at 40 to 60 feet intervals, while snow present on the ground has been ploughed to facilitate the collection of more snow. None of these schemes have proved satisfactory for, as the Russian investigator W. G. Rotmistrov in his bulletin " The Nature of Drought " points out, such schemes were based on a false premise. Snow can only remain on the surface of the ground as long as the temperature of both snow and soil is below the freezing point. If the soil temperature be above the freezing point part of its heat will be used in melting the snow and this moisture enters the soil. Such a condition is usually noticeable in the fall after the first snowstorm. As a rule, however, frost usually follows quickly after the first snowfall and the soil becomes frozen before the absorbed moisture can penetrate to any appreciable depth.

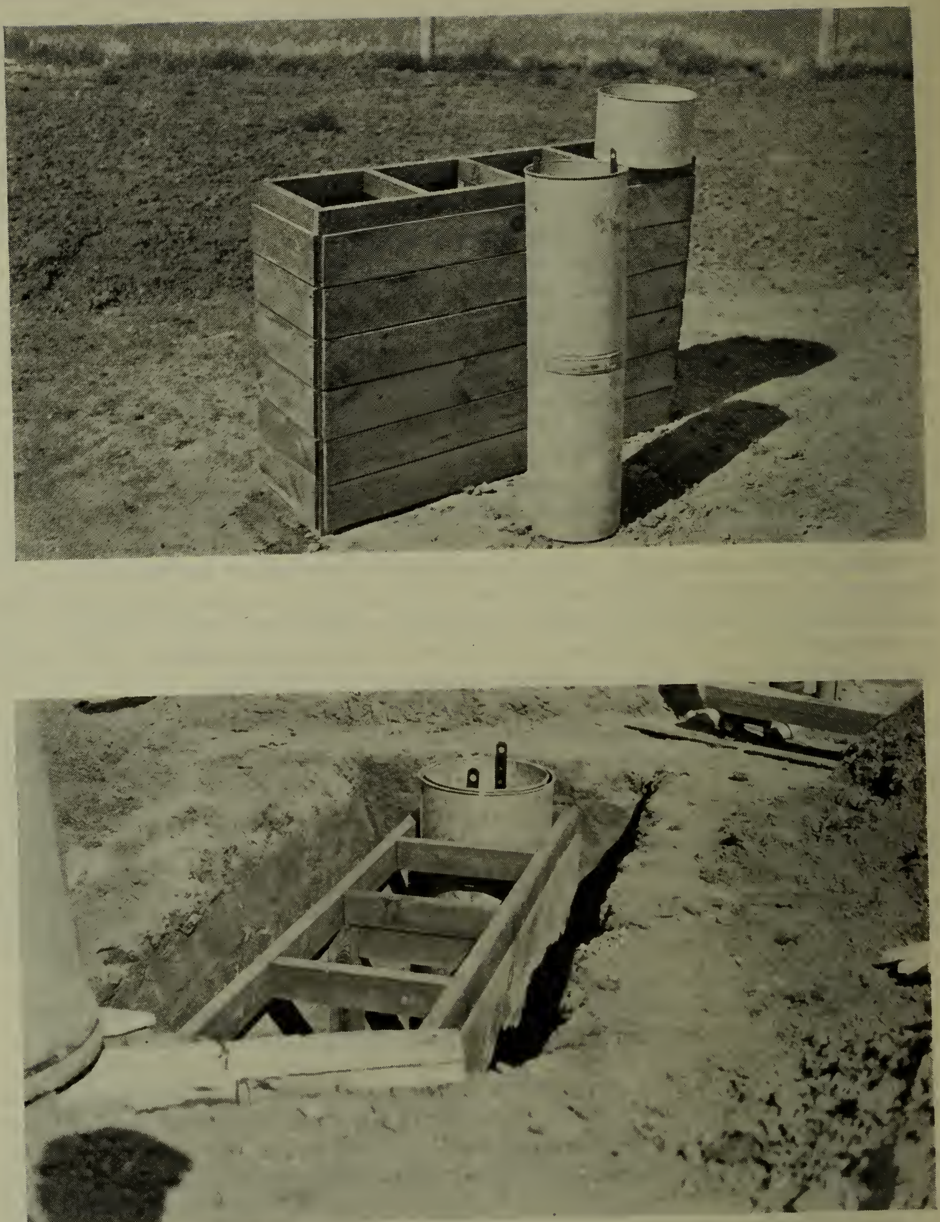
Snow will remain on the surface of the ground as long as the temperature of both remains below the freezing point. In the spring the presence of snow prevents the soil from thawing out. Moisture can only be absorbed by the soil when this is in an unfrozen condition. When such a condition arrives, of course, the snow has disappeared. It is significant that during the past seven years at Swift Current no appreciable increase in soil moisture has been observed from the presence of snow cover. Whatever increase had taken place could be ascribed almost wholly to rains which fell while the soil remained unfrozen. Confirmatory evidence on this point was available over an extensive area during the spring of 1928. The previous winter was peculiar in that practically all of the precipitation was in the form of snow. In many cases wheat seeded on spring ploughed stubble land either failed to germinate until after the first rainfall or came up in isolated spots across the field. What little moisture had been taken up by the soil during the winter and spring months had been dissipated by evaporation so that not sufficient was present to ensure germination. The snowfall at Swift Current on this occasion amounted to 21 inches.

Of the rain which falls a portion may be lost immediately by run-off. A series of light showers followed by warm weather may prove of little value in augmenting the soil moisture, as the water is quickly lost again by evaporation. The proportion of a season's precipitation retained by the soil cannot be determined readily but a careful study of the various factors indicates that not more than one-half can be effectively used by crops. This means that in the Swift Current district about 7½ inches of water would be available for crops as an average. Special means are employed, however, to increase this amount and these will be discussed under the heading of " the summer-fallow " on page 22.

EXPERIMENTAL METHODS USED AT SWIFT CURRENT IN THE STUDY OF SOIL MOISTURE

Two distinct methods are used in making soil moisture investigations. In one case small samples of soil are collected in the field to various depths. The amount of moisture in these samples is considered to be representative of the moisture present in the area investigated. The other method consists of noting the changes in weight of a mass of soil in deep watertight tanks. The tanks are arranged so that the soil surface is exposed to receive the natural precipitation. In the first method the amount of moisture is found by drying the soil samples in an oven, the change in weight indicating the moisture driven off. In the second the tanks containing soil are weighed periodically and differences in weight indicate changes in the quantity of water present, the amount of soil of course remaining unchanged.

In a field study of soil moisture samples have been taken from the first six inches of soil, the second six inches and from successive twelve-inch depths to a



Tanks used in soil moisture experiment.

total of four feet. The sampling tools are either a hollow steel tube of about one inch bore or an ordinary wood auger fitted with an extension rod and handle. The tube is provided with hardened steel ends and is driven into the soil to the required depth by a specially constructed hammer. It is then withdrawn and the core removed. On some soils, with a fair amount of moisture present, the tube is very useful in securing a large number of samples quickly. Under some other conditions, however, considerable difficulty has been experienced in withdrawing the tube and removing the core of soil, even though the tube point was provided with an internally expanding bore. The auger possesses the virtue of being cheap, and can be used for the purpose of securing samples from practically all types of soil under all conditions of soil moisture.

Where the land to be sampled is producing a crop, injury through tramping is unavoidable during the process of sampling. On this account the frequency of sampling and the number of samples from any particular plot have been reduced to a minimum. A series of samples, that is successive depths to four feet, is taken at each end of a field plot and the two samples of each depth are mixed to form one composite sample. The amount of moisture present in the samples is then considered to represent the condition of the whole plot to a depth of four feet. With the tanks, soil moisture loss or gain is measured by weight and the degree of accuracy is only limited by the sensitivity of the weighing apparatus. The scale in use at Swift Current is sensitive to one-quarter pound, although one-half pound is considered to be sufficiently accurate. One-half pound is equivalent to a rainfall of 0·08 inch.

The tanks used are made of No. 22 gauge galvanized iron and are fifteen inches in diameter, five feet deep, and are watertight. The depth of five feet was made to accommodate the roots of spring seeded crops. The diameter was limited by the capacity of the weighing equipment which is six hundred pounds. The tanks filled with soil are placed in groups of two in small pits; in a few cases four tanks are grouped together. Each group of tanks is surrounded by a small plot. The general arrangement of the tanks and plots is shown by the photograph on page 2. The tanks rest on two by four blocks at the bottom of the pits with the surface soil at approximately the same level as the surrounding soil. The pits are lined with a wooden cribbing which stops short of the surface by about nine inches. The remaining distance is covered by galvanized iron sleeves which encircle the tanks and leave about three-quarter inch clearance. The space thus formed was at first filled with felt to prevent the circulation of the air, but this precaution afterwards proved unnecessary. When the soil in the tanks is seeded to a crop, the small plots surrounding the tanks are seeded to a similar crop. The crops growing in the tanks are thus under approximately the same conditions as exist in the field. Details of the tanks and cribbings are shown by photographs of a four group set on page 10.

Soil is placed in the tanks to correspond as closely as possible with that in the field. During excavation the soil was placed in five separate heaps representing the surface six inches, the next three successive twelve-inch depths and the last depth of eighteen inches. Each heap was shovelled over several times to secure some measure of uniformity in the mass and the tanks were then filled in the proper order. During the process of filling the soil was kept well tamped.

The weighing equipment consists of a Fairbank's Butcher's meat beam of 600 pounds capacity. To accommodate weights in excess of this a small jockey weight is used to increase the capacity to 700 pounds. The scale, originally designed to hang from the wall, is suspended from a steel beam by a light chain at one end and by the lifting gear at the other. It is provided with a small spirit level so that it may be levelled when a reading is to be made. The lifting gear consists of a one-ton automobile jack with suitable suspension rods. Hanging chains or ropes are objectionable as damage to the crop results, but as the lift

Soil moisture experiments. Set of tanks ready for seeding.

required is only sufficient to permit the tanks to swing freely the jack serves this purpose very conveniently. Variations in ground level are compensated by a turnbuckle inserted between the jack and the steel beam.

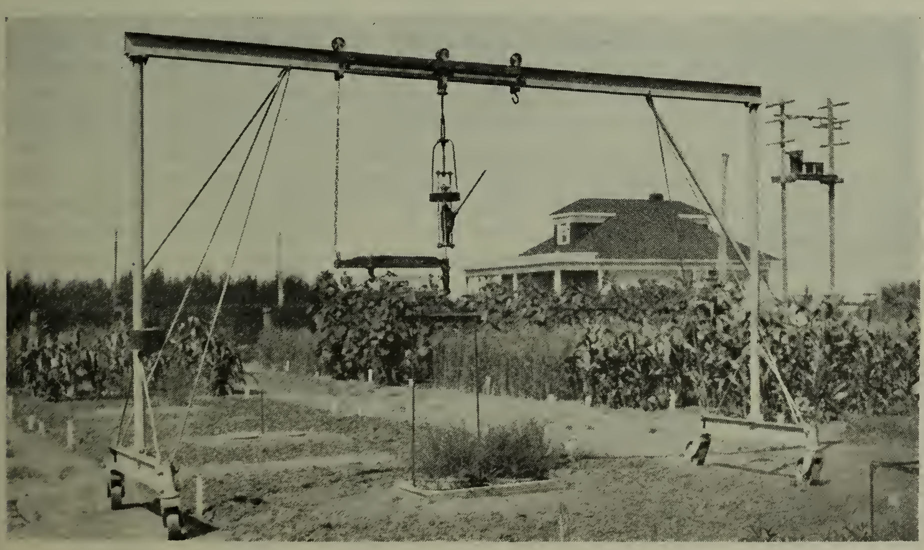
The steel beam carrying the lifting and weighing mechanism forms part of a gantry which completely spans the twelve-foot plots. The gantry was constructed with a length of light steel " I " beam two and one-half inches wide and five inches deep, supported at each end by pillars of two-inch diameter iron pipe provided with flanges at each end. The pillars are set on short pieces of " I " beam arranged at right angles to the longer cross beam. At each end of the shorter beams a large swivelling caster is attached. Brace rods, suitably located, complete the structure. The gantry can be moved from plot to plot by means of the four large swivelling casters. In addition the scale supports are fastened to small rollers so that the scale may be centered over each tank readily. Fastened to one column of the gantry is a small box containing a continuous roll of paper. The paper is inclosed within the box and is only visible through a narrow rectangular slot. In this manner the records are protected from wind damage. The weights as recorded are entered on the paper and the operators' hands are free to move the gantry as required. Two men are necessary to operate the equipment, but one man can carry on the work efficiently in case of emergency.

The casters merely run on the ground so that the gear cannot be operated in wet weather. As a rule, however, the surface soil when packed dries out very quickly after a rain and very little inconvenience has arisen from this source. The photograph on page 13 shows the construction of the gantry.

Crops are seeded in the tanks at the rate of 20 seeds for the grains and grasses, which is approximately the same rate as in the field, and one each for such crops as corn and sunflowers. Usually three times the amount of seed is used and the surplus plants are afterwards removed. The surrounding plots are seeded at the same time by means of a Planet Junior Seeder.

Wire screens are used to protect the crops against damage by hail or sparrows. Their effectiveness in preventing damage by hail is apparent from the photograph shown on page 35, which was taken after a hailstorm in 1923. Corn plants protected by the screen were not damaged during the storm while the exposed plants in the border plot suffered severely. Without the screens the grain crops would undoubtedly be destroyed by sparrows. These birds attack the grain of the border plots when it is in the late dough stage and very little is ever left to ripen. Each border plot in turn suffers from a massed attack by these little pests. The screens consist of a frame made of two seven-sixteenths diameter iron rods threaded at each end and bent to a " U " shape. These are fastened to opposite sides of a square frame of one by four inch wood by double nuts and washers. The corners of the " U " are spaced by five-sixteenths diameter rods having an eye at each end. The frame thus formed is covered on the sides by three-quarter-inch mesh poultry netting and on top with three-eighths-inch mesh sand screen cloth. The whole arrangement is light in weight and can be lifted on or off when the tanks are to be weighed. One screen provides protection for each pair of tanks. As practically all of the high winds come from a westerly direction, overturning of the screens is prevented by a simple hooked peg driven into the ground inside the screens and on the west side. The screens apparently do not prevent rain from reaching the soil in the tanks as a rain-gauge placed under one of the screens, checked in its reading with a similar gauge in the open a few feet away. The wire of the screen undoubtedly shades the crop to some extent, but its influence on crop growth is too slight to be noticeable.

The tanks are weighed at seeding time, as regularly as possible each week afterwards and at harvest. The difference between the initial and final weights indicates the water lost by the soil through evaporation and transpiration by the plants. Intermediate weights give an idea of the rate of use of water by the crop. The water lost from the soil added to that which fell as rain constitute the total water used to produce the crop. No account is taken of the weight of the crop in these calculations. Reduced to dry material the weight of the crop from such a small area is not sufficient to cause any appreciable difference in the weight of the water used.



Travelling gantry supporting lifting and weighing gear.

A COMPARISON OF EXPERIMENTAL METHODS

Of the two methods used in soil moisture studies at Swift Current, the results secured from moisture determinations on soil samples taken from field plots have not been comparable with those secured by the use of deep water-tight tanks.

While the method of studying moisture by the use of soil samples may appear to be suitable and comparatively simple, the results obtained have not been very encouraging. Soils often vary to a surprising degree, sometimes over comparatively small areas and variations in the amount of moisture present may also be quite marked. A spot once sampled cannot be sampled a second time. In order to detect what moisture changes have occurred in the soil after a previous sampling it is necessary to choose another location for a new sample. The average results from a considerable number of samples will, of course, tend to overcome the inherent variability in the soil moisture content, but this method is inadvisable both on account of the labour involved and also the unavoidable damage to growing crops.

Variations in soil moisture may be due to the unequal distribution of moisture in an otherwise uniform soil or to differences in the soil itself. A clay soil, as a rule, will show a higher content of moisture than a sandy soil when a test for total moisture has been made in the laboratory, while soils grading between these will show corresponding differences. These differences are caused by the property of soils to retain moisture against the suction power of crop roots. From the crop standpoint a clay soil would be quite dry when its moisture content was as much as 15 per cent. A sandy soil, on the other hand, would only indicate about 3 per cent moisture when in a dry condition. At 15 per cent moisture content a sandy soil would appear distinctly moist.

The term per cent in these cases refers to the amount of water compared to the amount of dry soil. In a soil containing 25 per cent moisture, 125 pounds of moist soil would consist of 25 pounds of water and 100 pounds of dry soil.

With suitable apparatus it is possible to classify soils according to their moisture retaining properties. In this apparatus, the action of which resembles that of a milk or cream testing machine, samples of soil previously saturated with water are whirled around at a certain definite speed. The centrifugal force created disperses a considerable amount of the soil water. That which is retained by the soil can then be determined. The factor obtained by this means is known as the moisture equivalent. As the moisture equivalent for clay soils is as high as 50 per cent and for sandy soils as low as 5 per cent the apparatus provides a convenient means for the classification of soils as well as the detection of soil variation. Two examples are presented in the following table. In each case the total moisture content of the samples as they were taken in the field appears in the first column and the corresponding moisture equivalent in the second column. The samples in each set were taken in level and apparently uniform summer-fallow land to a depth of twelve inches and at intervals of twelve inches. The figures have been arranged in order of magnitude.

MOISTURE CONTENT OF SOIL SAMPLES

Sample No.	Clay soil		Sand soil	
	Total moisture	Moisture equivalent	Total moisture	Moisture equivalent
	%	%	%	%
1	26·18	41·08	5·08	9·64
2	27·21	41·07	5·97	10·19
3	27·34	41·34	6·06	9·87
4	27·44	41·01	6·45	9·93
5	27·44	40·95	6·52	10·34
6	27·98	41·45	6·85	9·47
7	28·11	41·39	7·33	9·91
8	28·24	41·21	7·36	10·00
9	......	......	7·42	9·73
10	......	......	8·15	9·74

In both cases there was a maximum difference in the total moisture content of over two per cent whereas the moisture equivalent figures agree very closely. Where the number of samples has been greater the variations in total moisture have been correspondingly greater. In the following table some results of moisture determinations are presented in which apparently uniform summer-fallow soil was sampled to a depth of four feet at twenty points eighteen inches apart. The samples in this case were secured by means of a soil auger.

VARIATIONS IN MOISTURE CONTENT TO SOIL SAMPLES

Depth of sampling	Total moisture in per cent		
	Highest	Lowest	Mean
	%	%	%
0–6 inches	18·5	13·0	15·06
6–12 "	16·8	13·6	15·29
12–24 "	17·8	14·3	15·51
24–36 "	18·2	15·0	16·80
36–48 "	17·5	12·2	15·23

At another point thirty-four cores of soil were taken by means of a soil tube to a depth of four feet and at eighteen inches intervals, the whole cores being dried in the moisture determination. The results in this case varied from 20·5 per cent to 15·1 per cent with a mean of 18·7 per cent. In two other series, each of one hundred samples taken on summer-fallow land to a depth of twelve inches and at twelve-inch intervals, there was a range in one case of 10·4 per cent to 17·6 per cent of moisture and in the other from 12·3 per cent to 19·1 per cent. Several hundred soil samples have also been taken from plots, both on the Swift Current Station and on the other prairie farms and stations of the Dominion Experimental Farms System, on sandy loam and clay soils. From the results of this work it is apparent that in the estimation of moisture changes by means of soil samples the data are only comparable with crop yields after a generous allowance has been made for the probable error.

Water taken up by the soil from a rainfall gradually percolates downward until the ground water is reached, unless taken up by plant roots or dissipated by evaporation. The rate of this movement is much greater in the case of sandy soils than clay soils. According to the work of Rotmistrov* water percolates through a fine textured soil at the rate of approximately six feet per year. Some results secured at Swift Current confirm this work. These results are given in the following table:—

TOTAL MOISTURE IN SOIL SAMPLES

Depth of sampling	Wheat stubble land	Summer-fallow land
	%	%
1st foot	18·63	23·63
2nd "	9·33	16·39
3rd "	8·79	19·82
4th "	13·15	15·87
5th "	10·79	13·39
6th "	12·49	13·37
7th "	13·43	15·46
8th "	13·99	14·28
9th "	14·62	14·54
10th "	14·40	15·28
11th "	14·63	14·26

* Previously cited.

The wheat stubble land had produced four successive grain crops without any summer-fallow intervening. The summer-fallow land was cropped in alternate years to wheat. The samples of soil were secured after harvest in 1929 and following a rainfall of 0·75 inch. Moisture taken up by the soil from this rainfall is apparent in the first foot. Some of this moisture will have penetrated into the second foot by spring. As a rule moisture taken up by the soil from after harvest and early spring rains rarely percolates deeper into the soil of stubble land than 24 to 30 inches. Percolation of moisture in the summer-fallow does not appear to have extended beyond the fourth foot. In the tank experi-

Effect of moisture on growth of summer-fallow at both sides of plot. Additional moisture supply available.

ments percolation is restricted to a depth of five feet, but it would appear that this depth is only exceeded in summer-fallow and in seasons of higher than average rainfall.

The upward movement of water through the soil by capillarity is limited in distance and extremely slow in action. It is out of the question in dry-farming soils where free water occurs only at considerable depths. Experiments have shown the maximum height of movement of water through soil by capillarity to be ten feet and the time required to reach this height sixteen months (†) Moisture in the form of vapour moves up from the deeper soil layers and condenses near the surface. This phenomenon has been noticed every spring in the soil moisture experiments at Swift Current. At this time the outer surface of the tanks, just below the ground level, is covered with hoar frost. The frost originates from vapour arising from the subsoil and condensing on the metallic surface of the tanks. The amount of moisture moving in this manner does not appear to be appreciable as the following data indicate.

These represent moisture contents of soil samples taken at four closely adjoining points on the Swift Current Station. These samples were taken in the fall of 1929.

† "Soils" by E. W. Hilgard.

MOISTURE CONTENT OF FIELD SOILS

Depth of sampling	Summer-fallow	Prairie	Alfalfa	Wheat stubble
	%	%	%	%
1st foot	17·65	8·41	9·47	7·47
2nd "	19·75	6·78	7·97	8·35
3rd "	14·15	8·70	6·31	7·72
4th "	10·13	7·86	6·22	6·40
5th "	11·34	6·52	5·48	5·98
6th "	14·50	6·30	5·31	5·02
7th "	19·48	7·52	6·20	4·36
8th "	15·85	9·28	6·14	5·79
9th "	13·56	11·56	6·71	6·22

The land represented above was broken in 1921. The alfalfa was seeded in 1923 and has remained since that year. The prairie represents a small strip of virgin land bordering a small shallow draw used to take off the spring thaws. The figures in the last three columns represent dry soil conditions. The prairie soil has been dried out by the grass roots and the alfalfa roots have produced a similar condition. The condition of the wheat stubble land is such that the same explanation does not hold as the roots of spring grains do not extend beyond a depth of from four to five feet. The history of this particular piece of land indicates that it was broken in 1921 and was seeded to fall rye. After this crop was removed in 1922 the land was used for a crop sequence experiment in which the particular area sampled bears a succession of crops in the order corn, wheat, oats, none of which is a deep rooting crop. The only possible explanation for the dry subsoil is that this represents a condition existing since the land was broken in 1921. Continuous cropping has prevented any moisture from percolating beyond the root zone. At the same time no moisture has moved upward by capillarity.

The use of soil contained in tanks as a method of studying soil moisture is open to criticism for several reasons. The crops grown in these tanks are subject to conditions radically different from those in the field. The soil has been moved, stirred and thoroughly aerated to a depth of five feet. In filling the tanks the original soil structure cannot be restored. As the soil column is out of contact with surrounding soil the movement of moisture is restricted. Percolation of moisture beyond the five-foot depth is impossible and the upward movement of water is prevented. While all of this is undoubtedly true, its effect upon the soil is difficult to state definitely. Some of these criticisms have already been answered in the previous discussion. Possibly the best answer can be found in the crops grown in the tanks. For the first season such crops have not been as robust as those in the small surrounding plots. This may have been the result of some of the factors mentioned, but in the process of filling a certain amount of drying out took place and moisture conditions in the tanks, therefore, would not be as favourable as those in the plots. Experience during successive seasons supports this view. Grain crops seeded in the tanks are now the equal in vegetative growth and yield with those in the surrounding plots. Evidence of this fact can be seen in the photographs on page 21 and the yields of grain on page 22. Equal success cannot be claimed for such crops as corn and sunflowers. Normal development has not been possible in tanks only 15 inches in diameter. To overcome this defect tanks having double the surface area with the depth of five feet have been installed. The results from the use of these will be discussed on page 34. The use of soil contained in deep watertight tanks has provided a convenient means for the study of moisture changes in cropped and fallow land under the peculiar climatic conditions of southwestern Saskatchewan.

SOIL MOISTURE AND GRAIN ROTATIONS

A number of the tanks described on page 10 are grouped so that each pair forms one year in a crop rotation. Nine rotations are in use ranging from the simple two-year rotation of wheat and summer-fallow alternately to a seven-year rotation including, besides wheat, such crops as fall rye, brome grass and corn. Wheat is also being grown year after year in the same soil. By this means it is possible to learn, among other things, how much water is used by a crop, how much remains in the soil after a crop is removed, the moisture conserved by the summer-fallow and the amount derived from the winter's precipitation.

As the action of soil moisture is practically the same where grain crops only are used in the rotation the discussion on soil moisture and grain rotations will be limited to a rotation typical of the more extensive wheat-producing sections. This rotation consists of two years wheat and one of summer-fallow. One-third of the area is seeded in the spring on land previously summer-fallowed, one-third to wheat following a crop of wheat and one-third is ploughed and cultivated throughout the season as summer-fallow.

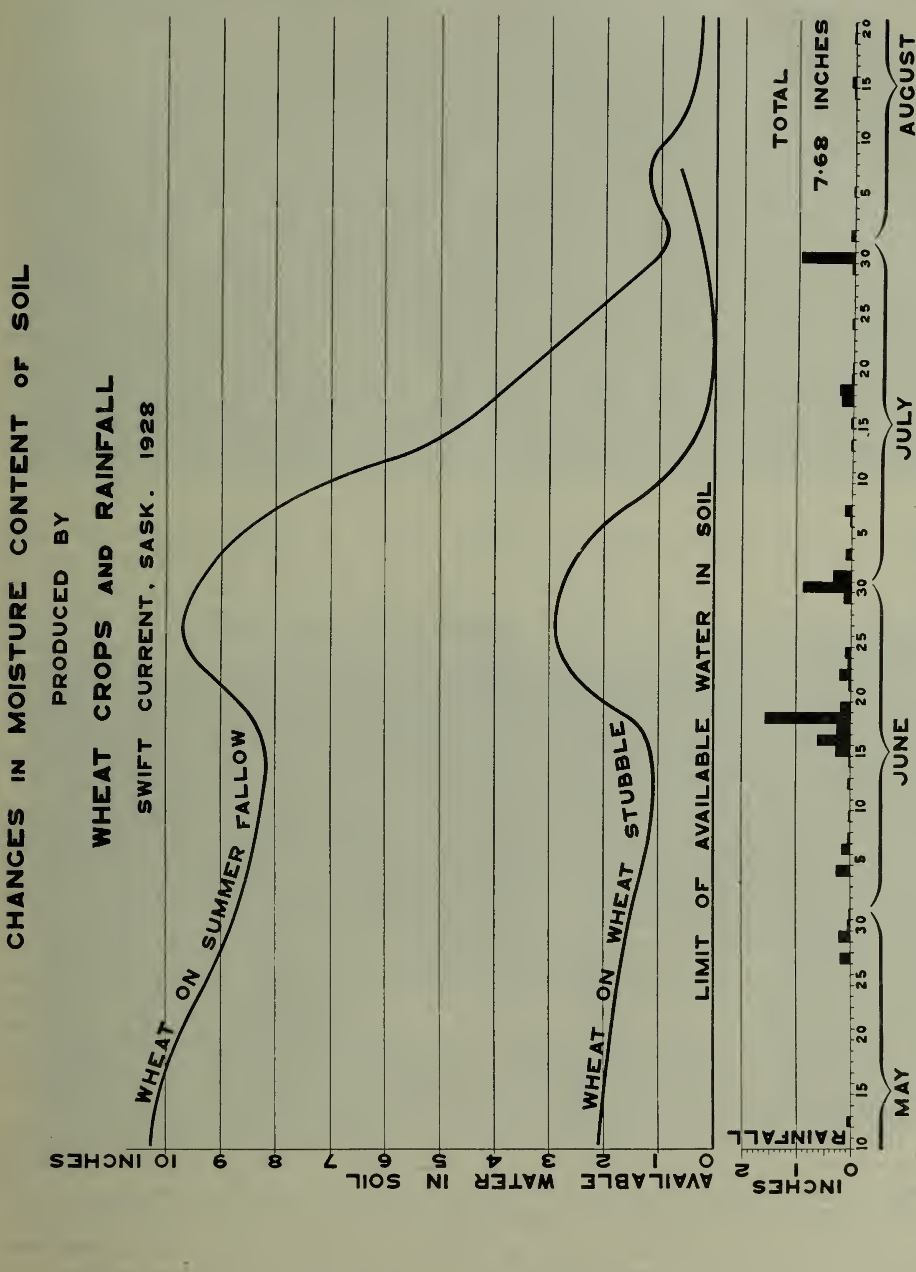
The tanks and border plots are seeded to Marquis wheat in the spring to coincide with field operations. Care is taken to keep down all weed growth throughout the season. As growth of the crop progresses no appreciable loss of water occurs from the soil until the plants are from three to four inches in height. Under the most favourable conditions for growth the rate of use of water increases until a maximum is reached at about the time of heading. This high rate is maintained until ripening sets in, when it diminishes rapidly.

The most favourable conditions for growth, however, occur but seldom. As a rule, the rainfall is quite insufficient to maintain normal vegetative growth and the plants are compelled to draw upon the reserve moisture in the soil. As this becomes less the plants have to adjust themselves to the deficiency. The adjustment may be manifested by a wilting of the leaves or a premature heading out of the plants. Moisture deficiency at any period of crop growth will of course be reflected in the subsequent yield. According to the results of experiments conducted in Russia the yield of wheat subjected to drought, when the plants were in the shot blade stage, was only 50 per cent of that which was grown under favourable conditions. Wheat subjected to drought when in the heading out stage was reduced in yield to 34 per cent, and that in the late milk stage to 77 per cent of wheat grown normally.

Usually the crop makes very effective use of any available moisture in the soil in addition to that which falls as rain. If the initial moisture content of the soil be sufficient or if abundant rainfall comes during the early part of the growing season, to stimulate a heavy crop growth, the soil at harvest time will be practically exhausted of moisture, as far as crops are concerned. This is particularly true if the rainfall be light during the later period in the growth of the crop, a condition which prevails, on the average, in the district in which these experiments have been made.

The chart given on page 19 traces the rate of loss of moisture from soil seeded to wheat in 1928 in a wheat, wheat and summer-fallow rotation. The chart is in two portions, the lower referring wholly to rainfall and the upper portion to moisture changes outlined in the text. Rainfall is indicated by a number of black columns at various heights. The base line upon which these columns stand is marked off to represent days of the month reckoning from May 10 to August 20. Days on which rain was received are indicated by a black column, while a scale indicates the height of each column in inches or the amount of rainfall.

The upper portion of the chart denotes moisture conditions in summer-fallowed and spring-ploughed wheat stubble land, respectively, with both seeded



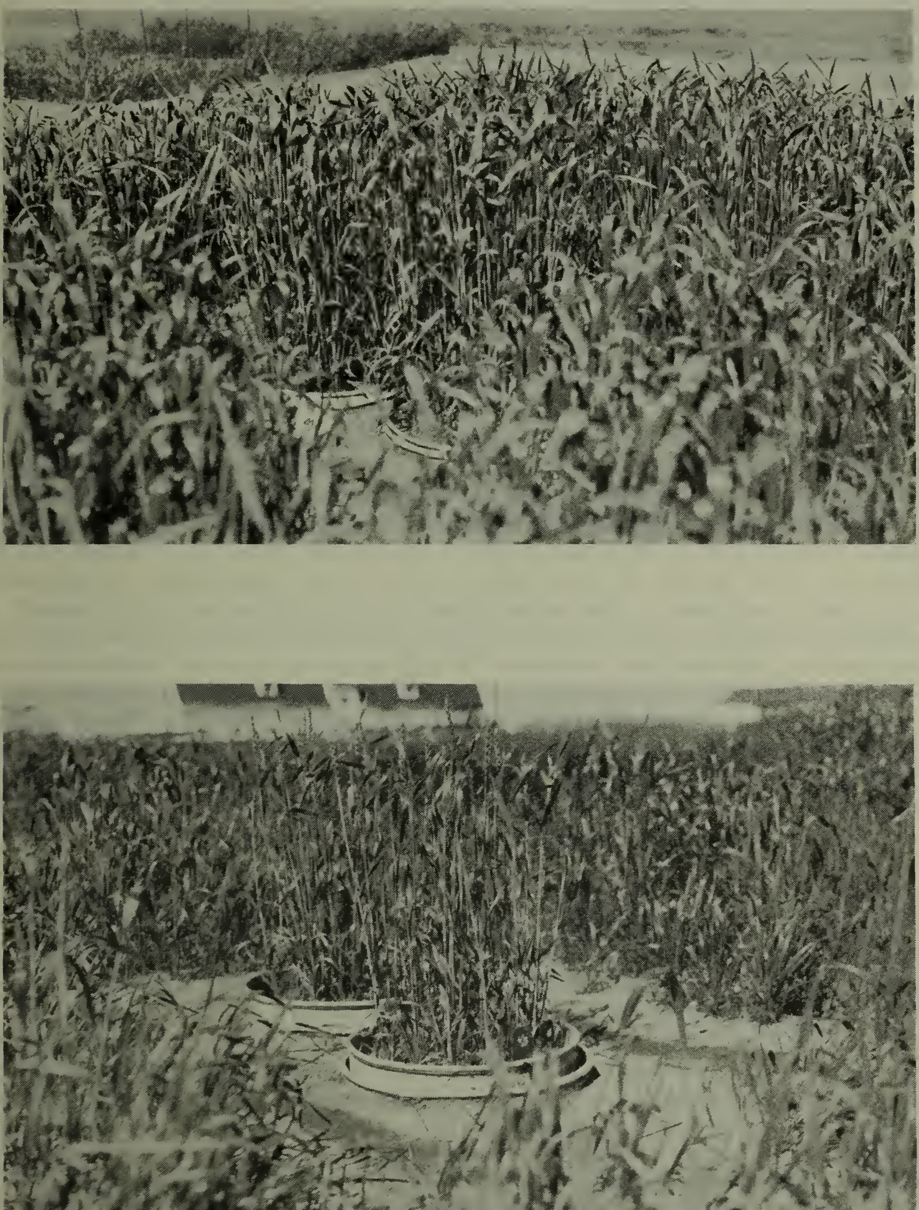
Change in moisture contents of soil produced by wheat crops and rainfall.

to wheat. At seeding time the former contained 10·28 and the latter 2·08 inches of available water. This water was distributed in columns of soil fifteen inches in diameter and five feet deep contained in tanks. In the case of the stubble land the available moisture was probably distributed near the surface in a manner described on page 16, with a zone of practically dry soil beneath.

The amount of available water given above has been estimated in the following manner. During seasons favourable to crop growth the soil is exhausted of soil moisture to a greater degree than in hot, dry seasons. This is probably due to a superior growth of crop roots in a favourable season. The degree of moisture exhaustion is of course indicated by the total weight of the tank and soil. For the purpose of determining the limit of available moisture, therefore, the lowest weight indicated by the tank during previous seasons is used to represent the point of minimum exhaustion of water by a crop. The difference between this weight and the actual weight of the tank at seeding time represents the amount of available water in the soil. Expressing the weight of water in the more convenient form of inches, as shown on the chart, is merely a matter of calculation. This method, it is believed, permits of a more accurate study of moisture than by the use of the wilting and hygroscopic coefficients. In the case of the former it is unlikely that the moisture in the surface and subsoil would reach the wilting coefficient at the same time. It is also possible for the surface soil moisture content to fall below the hygroscopic coefficient, where theoretically growth should cease, while the subsoil moisture was still present in sufficient quantity to maintain crop growth.

As growth progressed both crops began to use water from the soil. This is indicated by the downward movement of both curves. It is interesting to note that several showers were received during the period between May 27 and June 9. These, however, were not sufficient to meet the moisture needs of either crop. The effect of rains coming between June 15 and 19, in all 2·89 inches, was quite marked. The utilization of soil moisture was checked, in fact an appreciable addition was made to the available moisture as well as sufficient for the immediate needs of the crops. By June 20 both crops had made considerable growth and the transpiration rate, or rate of use of water, was correspondingly higher. Both curves dip downward after June 25 and the rainfall of 1·34 inches coming between June 29 and July 1 made apparently no appreciable modification to the amount of available moisture in the soil. It is very significant that the wheat crop seeded on summer-fallowed soil removed water at the rate of 0·42 inch daily for the seven days between July 9 and 16. The total rainfall during this period amounted to only 0·04 inch. On July 21 the curve representing wheat on wheat stubble touches the line marked "Limit of available water in soil." At this point the supply of soil moisture was exhausted and with it all further growth of the crop promptly ceased. The crop, it is true, retained its green appearance for several days later, but subsequent rains merely resulted in the storage of moisture in the soil without benefit to the crop. On the other hand, the crop on summer-fallow never exhausted the soil moisture completely. The rainfall of July 30 was distinctly beneficial and the crop was spared from a premature ripening.

The wheat seeded on summer-fallow in 1928 was able to utilize 10·05 inches of water from the soil, while the second crop of wheat secured only 2·08 inches. In addition there was the rainfall during the season amounting to 7·68 inches. Part of this rainfall, particularly in the case of the smaller showers, was probably never taken up by the soil but evaporated into the atmosphere. A smaller amount was also probably lost from the soil by the same process. As it is almost impossible to differentiate between the amount of water actually used by the crop and that lost by evaporation, the crops, it is assumed, have used the whole amount. The photographs on page 21 show the condition of



Top, wheat on summer-fallow; bottom, wheat on second crop after summer-fallow. Moisture deficiency has caused crop to head out. Compare appearance with crop in top photo.

the two crops on July 6. The luxuriant growth of the fallow crop is quite apparent. Note the fewer leaves on the second wheat crop and also that this crop has headed out, although both were seeded on the same day. The photograph shows that the wheat in the border plot surrounding the second wheat crop, or the stubble crop as it is usually called, is not developed to the same extent as that in the tanks. The border crop, drilled in with a Planet Junior Seeder, could not be seeded to as great a depth as that in the tanks, in fact the seed was placed near the surface in practically dry soil. As a result the crop in the tanks came up and for a time was surrounded by an area of practically bare soil.

The season of 1928 was an average one as far as rainfall was concerned. Between April 1 and July 31 there was a total of 7·89 inches of rainfall, while the forty-year average for the same period is 7·94 inches. That this amount is quite insufficient to produce a satisfactory crop is evident from the chart, shown on page 19, for the wheat seeded on summer-fallowed land utilized a much greater quantity of moisture from the soil than was received as rain. The yield of grain from the fallowed land was 2·8 times as great as that from the stubble land and the former had 2·03 times as much moisture available. While it would be incorrect to infer that the difference in yield was wholly due to the extra moisture this factor was undoubtedly the most important. This opinion is supported by the fact that in seasons of unusually heavy precipitation the yields of grain from summer-fallow and stubble land are more nearly equal.

The foregoing remarks have been based entirely on the results of crops grown in deep tanks. It is no doubt of interest to know what degree of confidence may be placed in these results and to what extent they coincide with actual field conditions. The photographs on page 21 indicate that growth is not restricted in any way by the use of this method of soil moisture study and the yields of grain confirm this view. When the yields of grain are expressed on an acre basis those from the tanks invariably harmonize with field plot yields.

This point was demonstrated by seeding to wheat four areas, equal to that of the tanks, in one of the plots in such a way that no border effect was possible. These areas when harvested produced, respectively, 42·8, 43·8, 44·3, and 48·3 grammes of grain. The yields from the two tanks were 46·5 and 45·3 grammes.

THE SUMMER-FALLOW

Enough has probably been presented to indicate that the summer-fallow performs a very important function in the grain growing sections of Western Canada. The practice of summer-fallowing is undoubtedly fundamental to successful grain production in sections where moisture is not abundant.

The summer-fallow is by no means a modern institution but has come down through the ages. The practice apparently was not always for the purpose of conserving moisture as the ancient injunction—" Break up your fallow land and sow not among thorns", suggests the use of the fallow as a means of weed eradication. European countries for a long time used the fallow for this purpose, although at present, root crops or other crops requiring frequent cultivation answer the same purpose more economically. In Western Canada the use of the summer-fallow as a means of conserving moisture appears to have been more or less the outcome of pure chance. Alexander Ross in his book, " The Red River Settlement, its Rise, Progress and Present State", mentions under date June 10, 1852, " on finding my crops falling off greatly, I tried the fall ploughing and summer-fallowing to some considerable extent, and it generally answered so well that I became anxious to see it introduced throughout the colony". It appears from this that Ross recognized the value of the summer-

fallow, but not as a means of moisture conservation. Some time later a series of incidents again demonstrated the value of summer-fallowing. During the Riel Rebellion of 1885 horses were in great demand to haul supplies for the troops. As a result Angus MacKay, later Superintendent for many years of the Dominion Experimental Farm at Indian Head, Sask., was unable to plough and seed a considerable area of stubble land early enough to escape the possible fall frosts. The land was ploughed, however, and received a few cultivations during the season to keep down the weeds. The following year proved to be very dry and crop failures were general everywhere except on the land fallowed during the previous year. The significance of this experience was not ignored. In his report of 1889 to the Director of Experimental Farms at Ottawa, Angus MacKay wrote: " Our seasons point to only one way in which we can in all years expect to reap something. It is quite within the bounds of probabilities that some other and perhaps more successful method may be found, but at present I submit that fallowing the land is the best preparation to ensure a crop". With this practice in general use on the prairies the recommendation now appears to be unnecessary, but the seasons have not changed, and as the more successful method has not yet been evolved, the summer-fallow will undoubtedly continue to hold its place so long as wheat forms the principal crop.

At some of the Dominion Experimental Farms on the prairies, the results of experiments have shown that wheat, in a suitable crop rotation, and especially following legume hay, but with no summer-fallow included, may give a yield equal to that in a grain rotation which includes the summer-fallow. These results, however, have been secured in districts where moisture deficiency is not of frequent occurrence.

Substitute crops have occasionally been suggested as a means of overcoming one of the main disadvantages of the fallow, the fact that the land produces no revenue. Where the moisture supply is of no concern this plan is quite feasible, in fact it is in general use in humid climates. On parts of the prairie, where rainfall limits the yield of crops, however, a summer-fallow substitute really means that two poor crops are substituted for one good one.

THE SUMMER-FALLOW AND WEED GROWTH

One of the points continually emphasized by Angus MacKay, formerly Superintendent of the Dominion Experimental Farm, Indian Head, Sask., and a strong advocate of the summer-fallow, was the need for careful preparation of the soil. The presence of any considerable number of weeds may entirely destroy the benefits sought by summer-fallowing. Some very surprising results have been secured on this point in the experiments conducted at Swift Current. Four tanks similar to those already described are seeded one year to wheat and the stubble land the following year is given different summer-fallow treatments. In one case cultivation only is practised. The other three treatments consist of ploughing at three different dates, on May 15, June 15, and July 15. After ploughing no weeds are permitted to grow. Ploughing in these experiments is similated by inverting the soil and stubble in the tanks to a depth of about four inches. The soil receives no preliminary treatment so that there is usually a good growth of weeds in the later ploughed land. It should be mentioned that no attempt is made in this experiment to plant weed seeds. In the soil cultivated only, no weed growth is permitted. That which is ploughed on May 15 has very little or no weed growth. The soil of the other two treatments is usually fairly well polluted at the time of ploughing. In this experiment emphasis is placed not so much on the time of ploughing as on the fact that this operation terminated weed growth in that particular soil. Under field conditions,

with cultivation to keep weeds in check, ploughing may be delayed. On some soils cultivating the summer-fallow without ploughing has given satisfactory results.

The figures in the following table show the increase in soil moisture in summer-fallow receiving various treatments during the period from spring until the time of the last treatment.

MOISTURE CONSERVED BY SUMMER-FALLOW, 1928

Treatment of summer-fallow	Total rainfall May 10 to July 15—5·90 inches
1. Cultivated only	Gain 3·45 inches
2. Ploughed May 15	" 3·06 "
3. Ploughed June 15	" 1·49 "
4. Ploughed July 15	Loss 1·18 "

For more detailed information on the amount of moisture conserved by the summer-fallow the reader is referred to page 26 of this bulletin.

The later ploughings show very significant differences when compared with the earlier treatments. The land ploughed on July 15 failed to conserve any of the 5·90 inches of rain and actually lost 1·18 inch of the water originally present in the spring. Weed growth was solely responsible for the variations in moisture shown in the table and as evidence that a very profuse growth of weeds is not necessary to cause an appreciable loss in soil moisture a photograph is submitted on page 25. This photograph shows the appearance of the soil before the ploughing on July 15. There were but three weed plants present, one of Western rye grass—a weed in this instance, one pigweed and one member of the androsace family, the last being the insignificant plant to the right of the picture. These three plants had accounted for all the moisture which might have been stored in the soil from the 5·9 inches of rainfall, as well as 1·18 inch of water originally present in the soil.

In the spring of 1929 the soil of all four treatments was seeded to wheat. At this time the following increases in soil moisture were observed:—

Treatment of summer-fallow	Gain in moisture
1. Cultivated only	5·5 inches
2. Ploughed May 15	4·5 "
3. Ploughed June 15	2·6 "
4. Ploughed July 15	0·8 "

These gains occurred during the period from harvest 1927 until spring 1929. A total precipitation of 16·65 inches was recorded during this time.

The yields of grain in 1929 from the four soil treatments agreed quite closely with the tabulated figures of moisture gain. These are set out in the following table. The actual amounts of grain harvested from fifteen-inch diameter tanks are of course small, so, for convenience, the yields in each case are expressed as a percentage of the first treatment.

Treatment of summer-fallow	Total crop	Yield of grain
	%	%
1. Cultivated only	100	100
2. Ploughed May 15	80	73
3. Ploughed June 15	64	66
4. Ploughed July 15	41	45

From the yields of grain and straw it is apparent that some of the grain from the No. 2 treatment was lost prior to, or at harvest time. The results are significant because the most potent factor in regulating yields has been the amount of available moisture, which, in turn, was influenced by weed growth. With this evidence the soil moisture conditions of the field shown in the photo-

Weeds established on late ploughed summer-fallow. These weeds used all the summer's rainfall.

graph on page 26 can be readily imagined. This photograph was taken on July 29, 1928. The unploughed land was covered by a dense growth of mature stinkweed.

Emphasis has always been placed on the necessity of having the summer-fallow well prepared. To be explicit, the land should always be free of weeds and in condition to absorb moisture readily. The soundness of this doctrine is

plainly evident in a dry season. In 1925 when the total rainfall between seeding time and harvest was only 3·65 inches, the early ploughed fallow produced twice as much grain as the late ploughed land. Ample rains during the growing period and varying degrees of weed infestation may tend to lessen the differences in yield. In 1928 with a rainfall of 7·68 inches during the season the late ploughed land yielded 29·6 per cent less than that ploughed early. In 1927 with 10·68 inches of rainfall both yielded approximately the same.

Poor method of summer-fallowing. Land worked too late.

MOISTURE CONSERVED BY THE SUMMER-FALLOW

How much of the rainfall is conserved by the summer-fallow? This depends on the distribution of the rainfall. A number of small scattered showers are not so effective as fewer but heavier rainfalls. High winds and warm weather following a rainstorm cause high losses through evaporation before the moisture has penetrated far into the ground. During the months of May, June and July, 1928, 3·06 inches of rainfall was conserved by the soil out of a total of 5·9 inches in well prepared summer-fallow. From July to the end of October there was a very small increase, the rainfall, however, only amounted to 2·57 inches during this time.

In the following table is shown the amount of precipitation and the proportion conserved by well prepared summer-fallow land during the years 1924-1929 in the soil moisture experiments at Swift Current. The table has been arranged so that the precipitation during the winter months is separate from that of the remainder of the year.

MOISTURE CONSERVED BY SUMMER-FALLOW

Period	Precipitation	Amount conserved	Total precipitation 12 months	Amount conserved	Per cent conserved
	in.	in.	in.	in.	
November 1, 1923 to May 16, 1924	5·70	0·66	17·31	5·46	31·5
May 16, 1924 to October 21	11·61	4·80			
October 21, 1924 to May 12, 1925	4·50	0·78	12·47	2·66	21·3
May 12, 1925 to November 2	7·97	1·88			
November 2, 1925 to May 12, 1926	2·91	none	13·42	2·45	18·3
May 12, 1926 to October 31	10·51	2·45			
October 31, 1926 to May 16, 1927	5·52	1·41	19·45	7·21	37·1
May 16, 1927 to November 1	13·93	5·80			
November 1, 1927 to May 10, 1928	2·27	none	10·74	3·11	29·0
May 10, 1928 to November 1	8·47	3·11			
November 1, 1928 to May 7, 1929	3·31	none	11·07	2·64	23·9
May 7, 1929 to November 4	7·76	2·64			

In a previous paragraph it was mentioned that a fallow period actually extends much longer than the term "summer-fallow" implies, from the harvesting of one crop, in fact, until the next is seeded. The chart shown on page 19 indicates that a crop of wheat, seeded in the spring of 1928 on land previously summer-fallowed, was able to secure from the soil 10·05 inches of water. According to the above table only 5·80 inches of water was conserved by the soil between the spring and fall months of 1927, when the land received summer-fallow treatment. The storage of moisture in the soil, however, began as soon as the previous crop was removed in 1926. The total moisture conserved, therebefore, includes the 5·8 inches and 1·41 inch shown above, together with 2·08 inches from the after harvest rains in 1926. The sum of these amounts, 9·29 inches, together with a small carry over 0·76 inch, unused by the 1926 crop, represents the total utilized from the soil by the wheat crop in 1928.

WHEAT YIELDS AS AFFECTED BY THE GROWTH OF WEEDS

Does the presence of weeds in a crop of wheat cause an appreciable lowering in the yield of grain. Experiments have shown that the influence of weeds on the yield of grain is probably next in importance to the moisture supply. In order to secure data on this point some tanks, similar to those previously described, were seeded to both wheat and weeds. For this purpose, seed of tumbling mustard, stinkweed and Russian thistle were selected. An attempt was at first made to have the weed and grain plants in a definite proportion, but the small size of the weed seeds made this impossible. The soil was therefore given a fairly generous seeding of weeds and these were allowed to do their best, or rather, worst. The grain was seeded at the usual rate to give twenty plants to each tank. An interesting point in connection with this experiment was that, while the growth of weeds in the field appears to be spontaneous, similar success could not be secured experimentally on the first attempt. The method now followed is to plant the weed seeds in the fall and the grain in the usual manner in the following spring.

The photographs on pages 28 and 29 show the effect produced by a profuse growth of Russian thistle among the wheat in the 1928 season and tumbling mustard in the 1927 wheat crop. Under field conditions the former would probably be considered a failure; harvesting such a crop would certainly be a difficult task.

Competition for soil moisture—wheat and Russian thistles.

The results secured in this experiment in 1928 are set out in the following table:

COMPETITIVE EFFECT OF WEEDS ON THE YIELD OF WHEAT
SWIFT CURRENT, SASK., 1928

Wheat and—	Total water used	Comparative weight of		Proportion of threshed grain to total crop	Total water to produce one pound of dry material	
		Total crop harvested	Threshed grain		Total crop	Grain
	in.			%	lb.	lb.
Russian thistle	15·5	162	38	8·3	243	2,930
Stinkweed	11·38	108	73	26·7	385	1,445
Tumbling mustard	14·2	108	86	28·2	335	1,190
No weeds	14·75	100	100	35·3	375	1,060

The influence of competition from the weeds is shown by the lower yield of grain, the lower ratio of grain to total crop and the higher water requirement of the grain. This is very pronounced in the case of the Russian thistle and wheat. Russian thistle is a plant very economical in the use of water, that is, it produces a large amount of material for the water used. This fact is reflected in the small quantity of water used, 243 pounds, for each pound of dry matter in the total crop. It is also quite evident that this growth was made at the expense of the wheat. The above table is not intended to bring out the relative influence of the weeds on wheat yields. In another season somewhat different results might be expected. The general effect of weed growth upon wheat yields, however, would be similar. Competition for moisture between wheat and weed plants would result in a lower yield of wheat.

Competition for soil moisture—wheat and tumbling mustard.

The same soil used in the above experiment was again seeded to wheat in 1929. No weeds were seeded on this occasion, for, as it afterwards proved, the pollution was very thorough. On this occasion only insignificant amounts of grain were harvested from the weed infested land. The results are given in tabular form below. For comparison the yield of wheat seeded on wheat stubble land free of weeds is also given.

COMPETITIVE EFFECT OF WEEDS ON THE YIELD OF WHEAT, SECOND YEAR WHEAT CROP, SWIFT CURRENT, SASK., 1929

Wheat and—	Total water used	Comparative weight of		Proportion of threshed grain to total crop	Total water to produce one pound of dry material	
		Total crop harvested	Threshed grain		Total crop	Grain
	in.			%	lb.	lb.
Russian thistle	6·24	113	30	7·5	765	10,600
Stinkweed	6·24	115	36	8·6	737	9,310
Tumbling mustard	6,71	86	17	5·4	1,067	23,075
No weeds	6·12	100	100	27·4	795	2,760

SOIL MOISTURE AS AFFECTING GRASS AND CLOVER CROPS

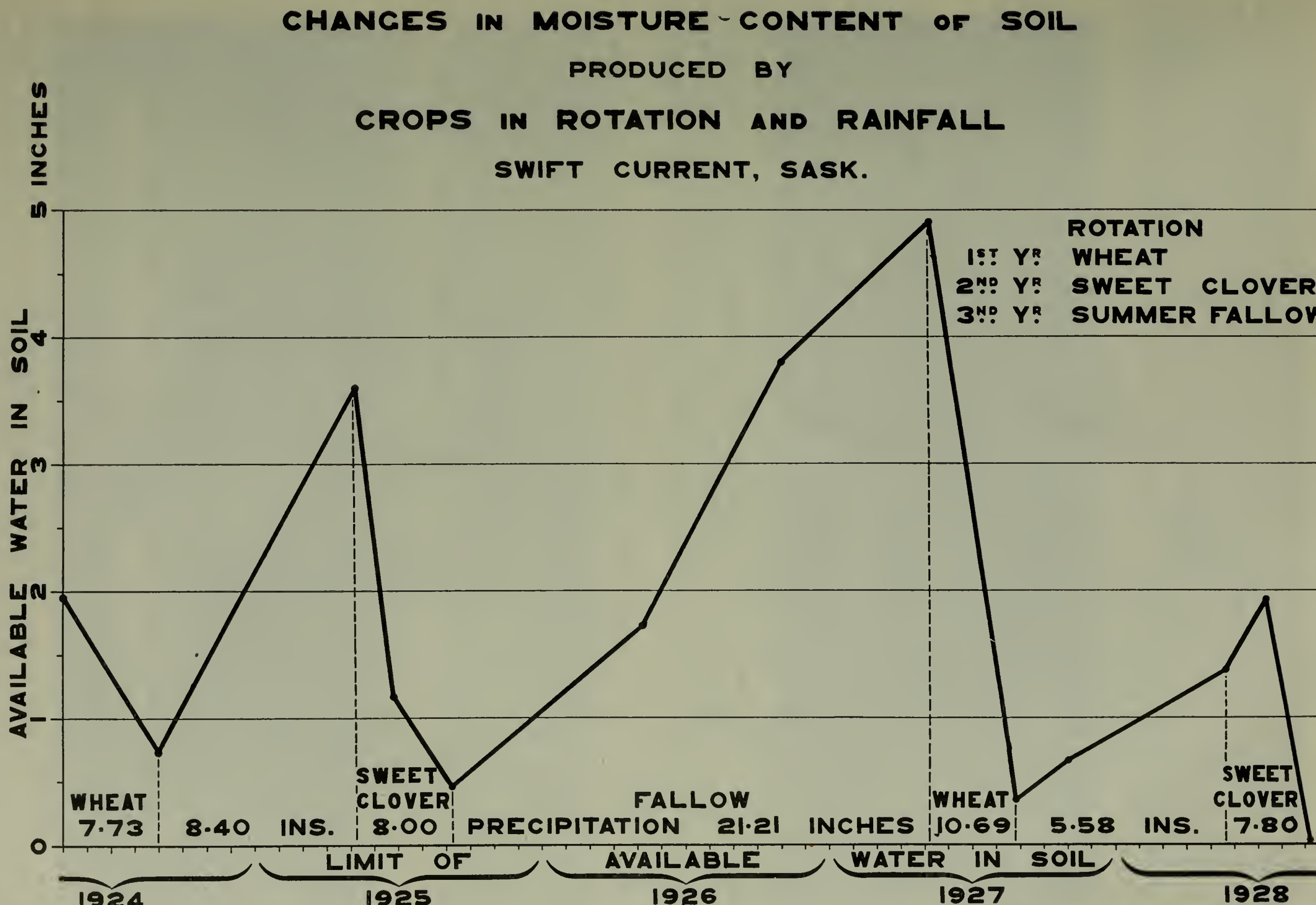
Grass and clover crops do not, at present, occupy a very prominent place in the agriculture of Western Canada. Of the whole area of cultivated land 96 per cent was used for grain production in 1926 and only three per cent for hay crops. However, a knowledge of the water requirements of these crops is of value in planning the sequence of crops in a rotation.

In Eastern Canada a very high proportion of the total cultivated land, 48 per cent, is used for the production of hay crops. One essential differece between the two sections, and one which has a marked influence on the growth of certain crops, is that of the distribution of precipitation or the relative amounts received each month. The chart on page 6 shows the average monthly precipitation at Swift Current, Sask., and Ottawa, Ont.

Precipitation at Swift Current during the fall, winter and early spring is relatively light while the greatest amounts are received during the summer months. The precipitation at Ottawa, aside from the increased amounts, is more evenly distributed throughout the year. As grass and clover crops are invariably seeded with grain crops and it has been already pointed out how the grain crop on the prairies exhausts soil moisture very thoroughly, the grasses or clover on the prairies, particularly in areas of deficient moisture, are placed under a severe handicap. In the spring there is a soil depleted of moisture and the prospects of only a meager rainfall until the season is well advanced. As a result hay crops on the prairies are subject to even greater difficulties with regard to a moisture supply than grain crops.

SOIL MOISTURE IN A WHEAT, SWEET CLOVER, SUMMER-FALLOW ROTATION

Included among the rotations used in the soil moisture investigations is a three-year rotation of wheat, seeded to sweet clover, sweet clover hay, summer-fallow. While this rotation would not commend itself to a farmer with a considerable area of grain land it serves the purpose of moisture study admirably. The sweet clover is seeded with the wheat on summer-fallow land. So far only



Changes in moisture content of soil produced by crop in rotation and rainfall.

fair success has been met in securing a stand of sweet clover owing to moisture deficiency. A good catch is secured but several of the young clover plants are unable to meet competition for moisture from the grain crop.

The chart shown on page 31 traces the moisture variations occurring in the soil each year under a rotation of wheat, sweet clover and summer-fallow. The chart indicates available water, in inches, present in the soil to a depth of five feet. Underneath each crop is given the amount of rainfall received during the growing period. This amount together with that taken from the soil represents the total water used by the crop. The chart also shows the extent to which soil moisture is depleted by the successive crops.

The soil has produced two crops of wheat and two crops of sweet clover while in one season it was summer-fallowed. As is usually the case, the soil loses its available moisture to the crop. Where one crop follows another it depends, for its moisture reserve, on the amount stored between harvest time and spring. Only when the summer-fallow intervenes is an opportunity provided for the soil to store moisture in any considerable quantity.

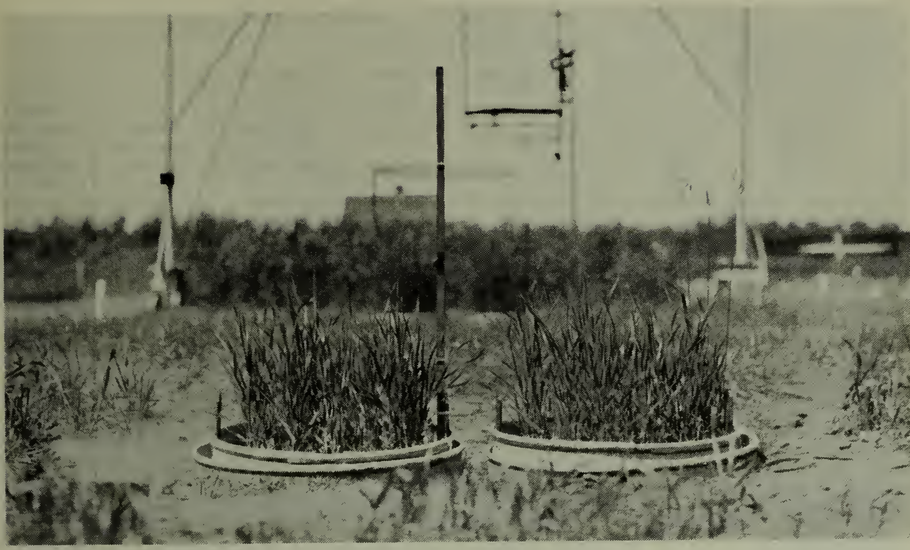
Remarkable growth was made by the sweet clover crop in 1928. The crop had remained practically dormant until the heavy rains commencing on June 16, after what proved to be the driest spring on record. This crop when cut on July 9 left the soil with slightly more moisture than was present in the spring. The stimulus of the rainfall appeared to have some after effects, for the aftermath, although very scanty, used up completely all the available soil moisture. The 1928 crop used only 442 pounds of water in producing one pound of sweet clover, reckoned on a moisture free basis. The aftermath used water at the rate of 1,010 pounds, which more closely agrees with results secured in previous seasons.

The wheat crop of 1928, in the rotation wheat, sweet clover and summer-fallow, was the largest during the past five years. This high yield, however, appears to have resulted from the amount of available moisture rather than from the fact that sweet clover had been grown in the rotation. The yield of wheat following a crop of sweet clover, when compared on the basis of amount of water used to weight of crop produced, was approximately equal to that of wheat seeded on summer-fallow in the wheat, wheat and summer-fallow rotation.

GRASS CROPS IN A CROP ROTATION

Grass crops react to soil moisture similarly to sweet clover. A seven-year rotation, in the experiments with tanks, contains two years in grass crops. The rotation consists of first year corn, second year wheat seeded to brome grass, third year brome grass hay, fourth year hay broken in July, fifth year wheat, sixth year summer-fallow, seventh year fall rye. No difficulty has been experienced in securing a catch with the grass seed, but the stands and yields of hay have not been very good.

A remarkable difference has been observed between the two hay crops in 1927 and 1928. The first year hay crop, although receiving more moisture than the second, produced less crop. The amount of water used for each unit of dry material also showed a wide variation. The cause of these differences is not apparent but it is probably connected with the root development of the crop. The comparative growth of the first and second year hay crops in 1928 is shown



Brome grass seeded previous year with wheat.

Brome grass second year hay crop.

by the photograph on page 33. The yields of hay and quantities of water used are shown in the following tables:—

THE USE OF WATER BY BROME GRASS

First Year Hay Crop

Year	Yield of hay (oven dry weight)	Total water used by crop	Pounds water to produce one pound of dry hay
	grams	in.	
1927	29·8	12·1	1,177
1928	9·4	4·1	1,274
1929	9·7	4·9	1,452

Second Year Hay Crop

1927	35·5	5·34	437
1928	33·7	5·40	459
1929	18·6	6·67	1,039

In 1928 the first and second year hay crops were harvested on July 9, but in 1927 the second year crop was cut on June 20 and the first year crop on August 10. A comparison of the figures in the two tables brings out the striking differences between the first and second year hay crops. It should of course be mentioned that the above results have been secured where climatic conditions are often unfavourable to the production of satisfactory yields of hay.

CORN AND SUNFLOWERS IN ROTATION WITH WHEAT

Reference has been made on page 17 to the fact that crops of corn and sunflowers did not have sufficient space for normal development when grown in the fifteen-inch diameter tanks. In order to overcome this difficulty some larger tanks were used. These tanks have the same depth, five feet, but have twice the area, being 21 inches in diameter instead of fifteen inches. The tanks are filled with soil in a similar manner and one plant only is used in each tank. The weight of these tanks complete is approximately 1,200 pounds. This weight is of course much beyond the capacity of the weighing gear but, by means of a suitable arrangement, only half the load is actually borne by the scale. A short lever is suspended at one end from the overhead beam and from the scale at the other. The lifting gear on the tank is attached to the center of this lever. When the tank is raised, one half of the load is carried by the scale and the other half is borne directly by the overhead beam. The whole arrangement is shown by the photograph on page 37.

The large tanks permit a normal growth of both corn and sunflowers, but this provision does not appear to have resulted in a marked difference in the water used by the crops grown in the two sizes of tanks. The amount of water used for each unit of crop produced is set out in the following table. These figures have been calculated from the amount of water used and the dry weight of the crop.

RATIO WATER USED TO CROP PRODUCED

Year	Corn		Sunflowers	
	Twenty one inch diameter tanks	Fifteen inch diameter tanks	Twenty one inch diameter tanks	Fifteen inch diameter tanks
1926	393	404	697	617
1927	653	748	616	610
1928	496	416	494	549
1929	1,112	826	1,271	1,137

In all cases the crops have been grown in rotations in which corn and wheat and sunflowers and wheat were alternated.

Corn crop after hail storm, July 21, 1923.

A crop of corn is generally considered to be economical in the use of water. While this is true to the extent that corn produces a fairly large amount of material for the water consumed, a corn crop shows no decided inclination to economize if water is available and conditions are favourable to growth. As a substitute for the summer-fallow, in districts where moisture conservation is all important, corn has practically the same effect on soil moisture as a crop of wheat. An increase in the moisture content of the soil during the growth of a crop of corn has only occurred in the experiments at Swift Current in seasons of higher than average precipitation. On some of the Dominion Experimental Farms, in districts where the moisture supply is not a matter of great concern and corn can be grown successfully, this crop, in a suitable rotation receiving light dressings of farm manure, has not appreciably depressed the yield of wheat which followed below that secured from land previously summer-fallowed and unmanured.

Sunflowers appear to exhaust soil moisture even more effectively than does a crop of corn. In 1927, a season with considerably more than average rainfall, the sunflower crop used, in addition to the rainfall, 3·55 inches of water from

the soil. The needs of the corn crop on the other hand were met by the seasonal rainfall, in fact a portion in excess was stored in the soil. Wheat seeded after a sunflower crop usually has less soil moisture available than that following a crop of corn, although wheat seeded after a crop of corn is under less favourable conditions, as far as moisture is concerned, than that seeded on summer-fallow. The following tables indicate the influence of both corn and sunflowers on the yield of wheat. For comparison the amount of water used by wheat seeded on summer-fallow has been added.

WHEAT FOLLOWING CORN AND SUNFLOWERS

Fifteen-inch diameter tanks

Year	Wheat after corn		Wheat after sunflowers		Wheat after summer-fallow	
	Total water used	Yield of grain	Total water used	Yield of grain	Total water used	Yield of grain
	in.	grm.	in.	grm.	in.	grm.
1925	8·1	11·45	6·8	4·85	11·6	47·62
1926	9·7	19·26	8·2	11·29	14·3	33·12
1927	13·6	35·30	10·7	21·35	17·0	48·52
1928	14·6	40·95	7·8	15·13	17·5	47·62
1929	6·6	7·30	6·0	4·50	11·5	17·80

Twenty-inch Diameter Tanks

Year	Wheat after corn		Wheat after sunflowers	
	Total water used	Yield of grain	Total water used	Yield of grain
	in.	grm.	in.	grm.
1926	10·1	38·27	8·6	29·75
1927	10·5	56·20	13·6	58·55
1928	14·0	74·46	8·8	29·75
1929	8·0	22·00	6·9	12·15

THE WATER REQUIREMENTS OF CROPS

The water requirement of a crop is a factor denoting the amount of water consumed in the production of a unit quantity of dry material in the crop. It is usually expressed as the pounds of water used to produce one pound of plant substance when the latter has been reduced to a moisture free basis.

The term " requirement " is somewhat confusing, especially as there is no definite quantity of water used by any crop. In the soil moisture experiments at Swift Current, for example, a crop of wheat has been produced with as small an amount as 5·8 inches of water, as well as with varying amounts up to 26·0 inches. A more descriptive phrase would be the " relative water efficiency of crops ". The term " water requirement", however, is in general use on the American continent.

It is possible to classify crops with respect to the amount of water used in the production of an equal amount of dry material. This must not be taken to mean that crops having a relatively low water requirement are necessarily adapted to areas of light rainfall, but that with an equal amount of water available and other conditions for growth also equal a crop having a low water requirement will be more productive than one of relatively high water requirement. In each case all the available water would be consumed. Corn, for example, has a relatively low water requirement, but only under favourable conditions for growth and moisture supply.

Experiments to determine the amount of water used by crops have been made in various parts of the world. These experiments were planned to discover what effect was produced when crops were supplied with water in varying amounts. In these experiments care was taken to prevent evaporation of moisture from the soil and ensure that all water was consumed by the plant during its growth. It was found that the amount of water used, when compared to the amount of crop produced, was lowest when a certain quantity of water had been applied. If this quantity were increased or decreased the result in both cases was the same, an increase in the water requirement. It was also learned that other factors in addition to the water supply may act to produce a similar result. Soil fertility, temperature and humidity of the atmosphere, wind velocity and sunshine acting in combination produce marked changes in different seasons.

Lifting and weighing gear arranged to weigh 21-inch diameter tanks.

In calculating the water requirement of any crop two factors may be secured. One is usually termed the " Transpiration Ratio " and the other the " Evapo-Transpiration Ratio". The Evapo-Transpiration Ratio is calculated from the weight of crop produced and the total amount of water used. This water consists of the amount consumed by the plant together with that lost in various ways, such as, evaporation and run-off from the soil. In calculating the Transpiration Ratio account is taken only of the amount of water actually consumed by the plant. On this account the Evapo-Transpiration is higher than the Transpiration Ratio. The two factors are alike in one respect. They represent the relative efficiency of various crops in their use of water when crop growth is made under a particular set of climatic conditions.

From the figures secured in the soil moisture experiments at Swift Current the water requirements of some of the more common farm crops has been determined. This information is set out in the following table and also in graphical form by the chart on page 40. All crops mentioned in the table were entirely dependent upon the natural precipitation for their moisture supply. The figures indicate the number of pounds of water used to produce one pound of the dry material in the plant. As all crops contain more or less moisture at harvest time the calculations have been made with the crops reduced to a moisture free basis. The column marked " grain and straw " in the table represents the whole plant above ground. In these experiments no attempt has been made to include root growth, the crops being harvested to within approximately one inch of the soil surface. This refers also to crops other than grain crops.

WATER REQUIREMENTS OF CROPS—EVAPO-TRANSPIRATION RATIO

Ratio of Water used in Producing Each Unit of Crop

Water used represents amount transpired by crop together with that lost by evaporation

Year	Rainfall of season	Wheat on summer-fallow		Wheat after wheat		Wheat after corn		Wheat after sunflowers		Oats after wheat		Corn after wheat	Sun-flowers after wheat	Brome grass after wheat	Sweet clover after wheat
		Grain and straw	Grain	Grain and straw	Grain	Grain and straw	Grain	Grain and straw	Grain	Grain and straw	Grain				
1924	in. 7·73	460	1,300	953	2,073	....	....	....	....	685	2,633	430	724	1,340	862 1st cut
															520 2nd "
														606 (1)	860
1925	3·65	483	1,384	596	2,000	590	2,035	767	4,197	501	1,115	496	594	509 (2)	735
1926	6·00	425	1,249	745	2,173	679	1,983	810	2,100	671	2,423	405	617	1,127	1,610
														1,177 (1)	696
1927	9·97	421	1,006	487	1,182	458	1,115	486	1,451	452	909	748	489	437 (2)	584
														1,274 (1)	442
1928	7·63	339	1,056	447	1,437	373	1,030	496	1,492	532	1,187	416	549	458 (2)	1,011
														1,425 (1)	1,267
1929	....	556	1,974	820	3,007	887	2,629	1,080	4,089	1,179	4,725	826	1,137	1,040 (2)	
														1,163 (1)	956 1st cut
Average	....	447	1,328	675	1,973	597	1,758	728	2,660	670	2,165	553	685	611 (2)	712 2nd "

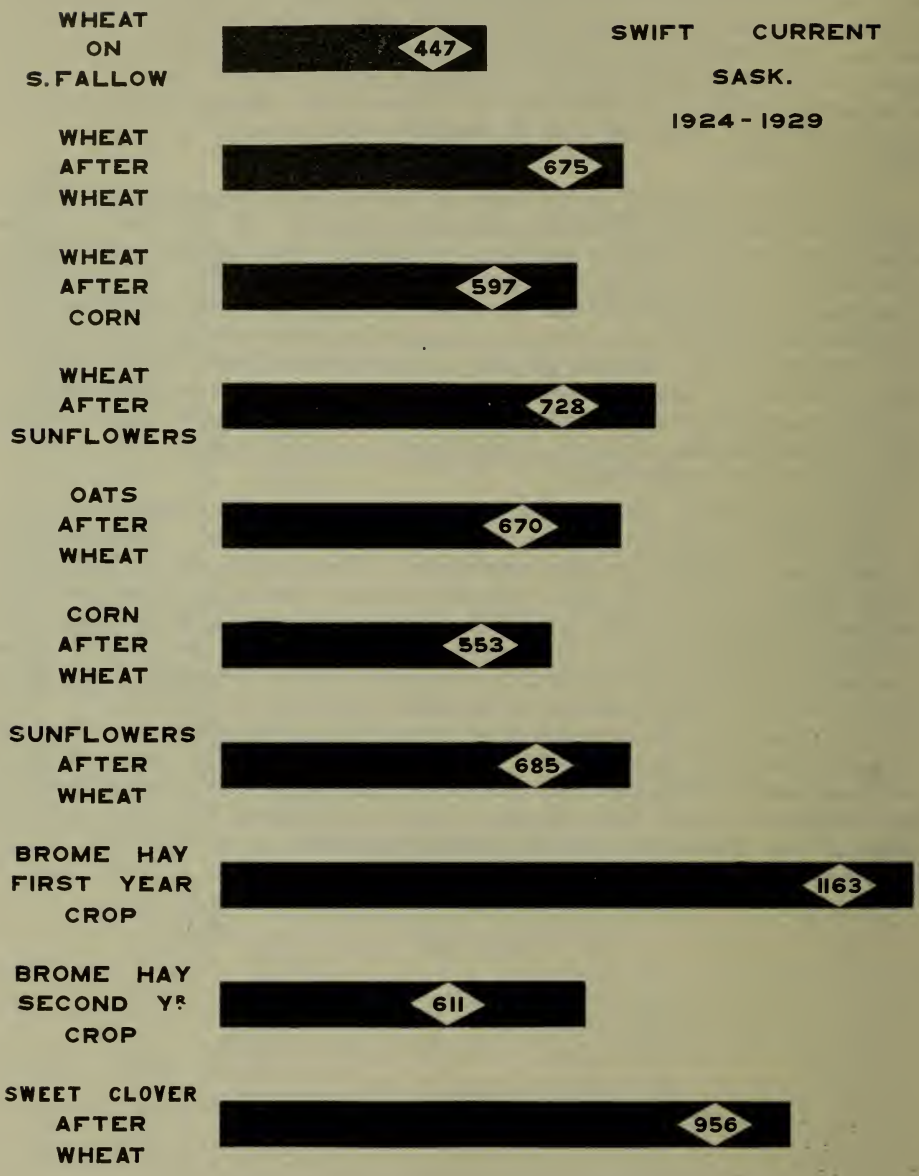
(1) First year hay crop. (2) Second year hay crop.

The tabulated figures have been calculated from the sum of the water removed from the soil and the total rainfall between seeding time and harvest. Water removed from the soil is understood to be that portion present at seeding time, but which is afterwards utilized by plant roots, as well as a smaller quantity lost by direct evaporation. All moisture from rainfall, of course, was not used by the plants. In very light showers the soil was scarcely moistened below the surface and evaporation probably dissipated this moisture before the plants could secure any benefit. The results secured in 1925 are evidence of the effect of moisture stored in the soil. Unusually heavy rainfall during October of the previous year resulted in a storage of available moisture in the soil. The total amount of water actually used by the crops in 1925 therefore was not as low as is suggested by the very light rainfall. This is also reflected in the moisture requirements data. The table represents fairly closely conditions which actually existed in the field.

The figures presented in the table are not directly comparable with those obtained in similar experiments by other investigators. In most water requirements experiments the object has been to learn the quantity of water actually absorbed by a plant during its growth. Care has been taken to prevent loss of moisture by evaporation from the soil. In many cases the crop was grown in surface soil only, while the moisture supply has been regulated to a constant point throughout the growing period. In the Swift Current experiments the crops have been produced entirely by the season's rainfall together with any available moisture present in the soil. As a rule the moisture supply at some time or other has been deficient, a condition, as already pointed out, which increases the water requirements.

For comparison a second table is presented showing the water requirements of crops grown in soil from which evaporation was prevented. A second series of tanks was installed for this experiment. These tanks are provided with closely fitting lids. In all other respects they are similar to those previously described on page 11. The metal lids are punched with holes through which the crops are made to grow. When crop growth has started the holes are closed by means of plasticene to prevent the entrance of rain. Through a hole in the centre of the lid water is added in amounts equivalent to the rainfall. Water lost from these tanks is all absorbed by the growing plants and the excess passed off in the process of transpiration. The water requirements of crops under these conditions can be calculated from the dry weight of material produced and the total amount of water added together with that removed from the soil. The results of this experiment at Swift Current are shown in the table on page 41. A table of results secured by other investigators is included.

COMPARATIVE WATER REQUIREMENTS OF CROPS



WATER REQUIREMENTS OF CROPS—TRANSPIRATION RATIO

RATIO OF WATER USED TO PRODUCE EACH UNIT OF CROP

Water used represents that transpired by crop only

Year	Rainfall	Wheat		Oats		Barley		Corn	Sun-flowers	Brome grass	Sweet clover
		Grain and straw	Grain	Grain and straw	Grain	Grain and straw	Grain				
	in.										
1924	7,73	324	851	307	897	321	858	174	290	862 (1)	1,108 (1)
1925	3·65	430	1,152	377	813	411	1,057	231	355	2,033 (1)	929 (1)
1926	6·00	379	1,077	314	717	298	578	181	368	444 (2)	273 (2)
1927	9·97	254	589	258	521	279	530	269	294	332 (2)	180, 257 (2) Two cuttings
1928	7·63	296	777	270	571	257	537	215	422	845 (1)	159, 189 (2) Two cuttings
1929	......	501	1,818	368	951	526	1,429	291	586	317 (2)	228
Average	......	364	1,044	316	745	349	831	227	386	......	......

(1) First season's growth. (2) Second season's growth.

WATER REQUIREMENTS OF CROPS—TRANSPIRATION RATIO

—	Wheat	Oats	Barley	Corn
(a) Hellriegel, Germany	359	401	297	....
(a) Leather, India	554	469	468	337
(a) Briggs & Shantz, Colorado, U.S.A	507	614	539	369
(b) Thom & Holtz, Washington, U.S.A	432	352	320	249
(c) Tulaikov, Russia	415	430	382	239

(a) From "The Water Requirements of Crops," by L. J. Briggs and H. T. Shantz.
(b) From "Factors Influencing the Water Requirements of Plants," by C. C. Thom and H. F. Holtz.
(c) From "The Plant in Relation to Moisture," by N. A. Maximov.

THE DROUGHT RESISTANCE OF CROPS

From an agricultural viewpoint the term drought is applied to that condition of the weather under which crops suffer through lack of moisture. A drought of this nature may occur in one or more forms. The season may at first be favourable and then become dry or only very light rainfalls may be received during the whole crop growing period.

Experiments have been made at Swift Current to determine the reaction of some of the most common farm crops to an artificial drought. Crops have been grown in soil provided with abundant moisture until growth was well advanced, when the addition of moisture was stopped. Provision has also been made to prevent rain from reaching the soil. As soon as all the available soil moisture had been used up and the crops had wilted severely water was added in order to find out which crops could recover. These crops were grown in tanks filled with soil so that it was possible to measure any loss of water in very small amounts. When the daily loss of moisture from each tank or the amount used by the crop was one-quarter pound, which would be equivalent to 0·04 inch of rainfall, the limit of available moisture was assumed to have been reached and water was then added.

Wheat, oats and barley have failed to make any recovery after the above treatment. These crops appear to adjust their growth as the water supply diminishes. When the low level has been reached the grains have headed out and have usually produced a small quantity of seed. Corn being essentially a dry land crop has withstood a long period without rain and has made fair recovery after the addition of water. The sunflowers have also survived a long period of drought but their appearance afterwards has not been very attractive. Usually the lower leaves wither and fall off leaving a long bare stem with a small cluster of leaves near the head. Under such conditions, or course, the yield of this crop is very small. Brome grass and western rye grass have made complete recovery after the application of water. Sweet clover has survived a severe period of drought during each year of its growth and the plants came through apparently uninjured.

The real test of the drought resistance ability of a crop is its power to yield when moisture is scarce. Under extreme conditions, of course, none of the economic crops can meet this requirement. Russian thistle, the pestiferous weed of dry land countries, appears to thrive under extremely dry conditions, but few crops share this ability. Grasses and clovers, while able to survive comparatively long periods without rain, yield so low under such conditions that they are unprofitable.

SOIL MOISTURE AND CROP FORECASTING

The general effect of rainfall upon the yield of wheat in Western Canada is well known, but as yet rainfall records have not furnished a reliable means for predicting crop yields. As a rule rainfall higher than the average in dry climates results in high yields, while in humid climates rainfall less than the average usually produces the highest yields.

Precipitation, unfortunately, does not occur in any organized order. In some sections the total annual precipitation may appear to follow some roughly defined cycle, but irregularities make it almost impossible to predict the next season's rainfall with any degree of certainty.

It will no doubt be of interest to study the relative effect of rainfall and moisture stored in the soil upon the yield of wheat. As the amount of available soil moisture can be determined in the spring, this information may serve as an index to crop possibilities. The figures set out in the following table were secured in the soil moisture experiments at Swift Current. While these experiments cover only five to six seasons these have been quite variable as far as precipitation is concerned. The table shows the amount of rainfall and the water removed from the soil during the growth of a crop of wheat.

WATER USED BY WHEAT ON SUMMER-FALLOW

Year	Total water used in.	Water received as rain in.	Water taken from soil in.	Relative Yield of grain 1927=100	Pounds water to produce one pound of total crop	Pounds water to produce one pound grain
1923	17·10	14·02	3·08	76	528	1,347
1924	13·36	7·73	5·63	69	460	1,300
1925	11·87	3·65	8·22	51	483	1,384
1926	13·08	6·00	7·08	68	425	1,249
1927	16·80	7·48	9·32	100	421	1,006
1928	17·40	7·63	9·77	98	339	1,056
1929	11·52	6·12	5·40	37	550	1,974

A crop of wheat, seeded on summer-fallow, usually exhausts the soil of all moisture within the root zone. The column headed "Water taken from Soil", therefore, represents the amount of available moisture which was present at seeding time. Comparing the seasons of 1925 and 1927 it will be seen that while the amount of soil moisture used does not differ very markedly, 8·22 and 9·32 inches respectively, the yields of grain differ by nearly 50 per cent. The significant factor is the difference in the amount of rainfall, 3·65 inches as against 7·48 inches. The 1923 results indicate that the reverse conditions may produce a similar result. High precipitation was accompanied by a low yield of grain on account of the small amount of available soil moisture. Very similar results have been secured where wheat has been grown after a previous crop of wheat. These are set out in the following table:—

WATER USED BY WHEAT ON STUBBLE

Year	Total water used in.	Water received as rain in.	Water taken from soil in.	Relative Yield of grain 1927=100	Pounds Water to produce one pound of total crop	Pounds Water to produce one pound grain
1924	7·88	7·73	0·15	34	953	2,073
1925	7·98	3·77	4·21	38	596	2,000
1926	8·00	5·96	2·04	35	745	2,173
1927	12·65	7·40	5·25	100	487	1,183
1928	8·65	7·39	1·26	57	447	1,437
1929	6·00	5·70	0·30	19	820	3,007

It is evident from the above tables that the presence of a comparatively large amount of moisture in the soil at seeding time does not afford a reliable basis on which to predict yields. Much depends upon the amount and distribution of the season's rainfall. However, a reserve of soil moisture is particularly valuable in sustaining the crop during the dry spells of summer.

THE INDIRECT EFFECT OF FERTILIZERS ON SOIL MOISTURE

While the application of superphosphate to small test areas of wheat lands in Western Canada has in some instances produced an increase in the yield of grain this increase does not appear to have been made at the expense of the soil's reserve of moisture.

According to the results of experiments made in Australia the application of phosphatic fertilizers to wheat results in a marked stimulation of the root development and an increase in vegetative growth. These two factors are usually accompanied with an increased rate of transpiration, or an increase in the rate at which water is used by the crop. In sections where the available soil moisture is limited and rainfall is deficient the stimulation of plant growth may only serve to accomplish the plant's ruin. The moisture supply is rapidly exhausted and the crop dies without reaching maturity. This has been observed in arid countries where fertilizers have been used. A similar occurrence has occasionally been noticed where wheat was seeded on old alfalfa land. Among farmers this phenomenon is known as " firing".

In view of the widespread interest created in experiments with the application of superphosphate and, in many cases, its apparent ability to increase the yield of wheat, it is of interest to learn what effect the stimulation in crop growth has upon soil moisture. A study of soil moisture conditions was therefore made in a clay soil and also in a light loam soil on which applications of superphosphate had been made. Untreated land was also examined for the purpose of making comparisons. In each case wheat was seeded on summer-fallow and treated and untreated lands were closely adjoining. Substantial increases in yields were secured from the land treated with superphosphate. From the clay land, treated and untreated plots respectively, yields of 28·0 and 21·1 bushels per acre were secured and corresponding yields from the light loam soil were 16·7 and 7·75 bushels per acre.

Soil samples for moisture determination were taken about six weeks after harvest. The rainfall during this time amounted to 1·33 inch, but was not sufficient to materially affect soil moisture conditions below the first foot of soil. The results of these determinations are set out in the following tables:—

MOISTURE CONTENT OF SAMPLES OF CLAY SOIL

Depth of sampling	Superphosphate		No superphosphate	
	Total moisture	Moisture equivalent	Total moisture	Moisture equivalent
	%	%	%	%
1st foot	22·08	43·34	19·29	39·76
2nd "	19·82	42·18	18·77	40·28
3rd "	22·07	42·62	20·13	43·60
4th "	27·68	43·84	24·46	43·99
5th "	32·91	48·15	27·34	48·26
6th "	33·18	46·01	27·52	44·50

The moisture equivalent data indicate a marked similarity between the treated and untreated soil. The figures for total moisture are surprising as slightly more moisture appears in the soil which produced the heavier crop.

MOISTURE CONTENT OF SAMPLES OF LIGHT LOAM SOIL

Depth of sampling	Superphosphate		No superphosphate	
	Total moisture	Moisture equivalent	Total moisture	Moisture equivalent
	%	%	%	%
1st foot	10·61	25·33	10·94	24·70
2nd "	8·02	22·82	7·99	22·08
3rd "	7·39	22·39	6·49	19·18
4th "	7·95	20·94	8·05	19·98
5th "	10·61	20·77	10·36	20·55
6th "	12·36	21·73	12·39	21·14

After making allowance for slight differences in soil composition at the two locations from which the samples were drawn and which are indicated by the moisture equivalent data, the total moisture appears to be approximately the same in each case.

The foregoing results are of interest as they indicate no greater utilization of soil moisture by wheat following the application of superphosphate than where no fertilizer was applied. Of equal interest also is the fact that stimulation of root growth in the fertilized soil, if such actually occurred, is not apparent from the soil moisture data.

CONCLUSION

The results of experiments described in this bulletin are particularly applicable to the western half of the province of Saskatchewan. This may be said to extend west of a line drawn between Moose Jaw and Saskatoon and on as far as the North Saskatchewan river. This area, according to the classification of the Provincial Department of Agriculture, comprises the crop districts Nos. 3, 4, 6 and 7. Swift Current is located within crop district No. 3. For the ten-year period from 1918 to 1927 the average yield of all wheat grown in the respective districts has been: No. 3 -15·2, No. 4-11·2, No. 6 -13·5 and No. 7 -13·9 bushels per acre. Over these areas the periodical occurrence of rainfall deficiency requires that great care be exercisd at all times in moisture conservation so that profitable yields of crops may be secured.

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